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Economic Impacts of Groundwater Salinity in Louisiana

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ECONOMIC IMPACTS OF GROUNDWATER SALINITY IN LOUISIANA

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfilment of the
requirements for the degree of
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in

The Department of Agricultural Economics and Agribusiness

by
Rajan Dhakal
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Abstract

In the United States, nearly 60 million acres of land is affected by water and soil salinity problems that pose a serious threat to the long-term economic and environmental viability of the agricultural sector. Understanding the economic impacts of soil salinity in agricultural lands is essential for planning farming practices in several salinity affected regions. This study utilizes a two-stage approach to assess the economic damage to crop production from salinity in two major aquifers (Chicot and Mississippi River Alluvial Aquifer) in Louisiana. In the first stage, looking at the trend of rise in salt content within these aquifers, I predict the future level of salinity by assuming three different scenarios. The three scenarios involve increase in water salinity level within the two aquifers at low, medium and high rate. In the second stage, I use the IMPLAN software to estimate the potential economic impact from the increasing level of salinity with and without using adaptive measures. In order to assess the potential economic damage to economy in future, I set a baseline economic scenario and compare the economic contribution of crop production in future under increased salinity conditions with the baseline scenario. The baseline scenario in this study is the current total economic contribution of major irrigated crop production on the economy of the study region. If the damage is assessed 30 years from now, the results show that increased salinity can result in loss of more than \$500 million in total output in the current value term. Furthermore, I find that adaptive measure using alternative cropping practices should be able to prevent a majority of this loss.

Chapter 1. Introduction

Salinization of water and soil is a common natural phenomenon and constitutes problem that humans have been facing for thousands of years (Hillel, 2000). In the Tigris-Euphrates River valley, the center of ancient Mesopotamian civilization, water and salinity were the main factors to cause population change, together with the rise and fall of cultural centers (Hillel, 2000). Among several recorded histories of soil salinization and its impact on human civilization, the most serious problem may have been witnessed in Mesopotamia (now Iraq) during 2400-1700 B.C with this being one of the earliest events recorded related to soil salinity (Jacobsen and Adams, 1958). In their study, it was mentioned that even the Babylonian story of 'Atrahasis', mentions salinization, referring to that condition as the "turning white of the fields". Since the advent of agriculture, salinization of water and soil proved to be a significant problem for agriculture. This problem increased with time in farm lands, due to various natural and human actions. Several environmental stresses affect the production of crops, such as extremities in temperature, flood, draught, wind erosions and soil salinity. Yet among these, the most ravaging one is soil salinity, which induces devastating effects by making arable lands uncultivable and decreasing the productivity of crops together with the quality of produce (Yamaguchi and Blumwald, 2005); (Shahbaz and Ashraf, 2013).

Rain-fed agricultural land comprises 80% of total agricultural land worldwide; the remaining 20% is under irrigated agriculture (Rockstrom et al., 2003). Irrigated agriculture is tentatively three times more productive than dry land agriculture. Thus, to meet the escalating demand of food, a rapid boost in food crop production through irrigated agriculture becomes a vital necessity. However, since development of soil salinity is more likely to occur when there is

prolonged irrigation, the productivity attained by irrigated agricultural lands still becomes inadequate to guarantee food security (Rasool et al., 2013). Therefore, soil salinity has become a major problem, which not only hinders the productivity of irrigated lands but also has become a big hurdle for global food security.

Soil salinization is the process of accumulation of salt in the upper layers of soil. Naturally, it occurs in those landscapes where evaporation exceeds precipitation (mostly in water deficit conditions) due to which the water is insufficient to leach out the salts from the soil profile (Duchaufour, 1982; Schofield and Kirkby, 2003). The Irrigation of crops using poor quality groundwater, as well as the absence of a proper drainage system in irrigated lands are the major contributing factors of soil salinization (Rasool et al., 2013). Natural salt deposition also contributes towards soil salinity development, which can occur by several processes such as weathering of rocks and minerals, deposition of wind-transported sands containing salts, seawater intrusion on nearby lands, and a rise of saline groundwater from shallow water tables due to capillary movement (Rengasamy, 2010). Farming practices such as the use of chemical fertilizers and the application of substandard quality irrigation water without treating for salts, are also responsible for accumulation of salts in soil (Rengasamy, 2010).

1.1 Problem of study

Every type of soil has some amount of salt in its profile, regardless of the quality of irrigation water applied or other human interventions. A moderately saline soil isn't necessarily harmful for agriculture, because most crops have some level of tolerance for salinity; these crops can perform basic physiological functions required for their growth and development, as long as the salt present in soil is within a safe level. However, for agriculture on a global scale, soil salinity

comes as a threat when salts depositing in soil surpass a level above which they become detrimental to crop production (Rengasamy, 2010). According to Maas and Hoffman (1977), the threshold salinity level of a crop is the maximum salinity that the crop can withstand without losing its yield. As the concentration of salt in soil transcends the threshold level of salinity, a gradual reduction in growth rate and plant size is observed (Maas and Hoffman, 1977; Maas and Grattan, 1999). As the amount of salt accumulated in soil escalates, the chemical, biological, and physical properties of soil start to become adverse for growth and development of crops, resulting in a gradual reduction in yield.

According to estimates, currently 20% of earth's land under irrigated agriculture is directly affected by salinity (Yeo, 1998). According to Rengasamy (2006), "All soil types with diverse morphological, physical, chemical and biological properties may be affected by salinity." However, salinity problems are relatively more common in arid and semiarid areas of world, due to the frequentness of drought throughout the year. Extremely low rainfall paired with an uncertainty of occurrence, make these regions marginal for crop production. Several regions throughout the world which used to be agriculturally productive have become wastelands made unfit for crop cultivation by the effect of salt. According to Rasool et al. (2013), among the total irrigated land in major countries with high agricultural productivity, either one third endure very poor salinity conditions or the future probability of these lands becoming salinized is very high. One can easily infer from these estimates that salinization of soil in productive lands is accelerating quickly throughout the world. If this problem is not eradicated or at least subsided to a certain minimum level, then the result will pose a significant threat to global food security.

In the present context, there seems to be a gradual increase in the level of salinity affecting soil in many areas of the world. According to Shrivastava and Kumar (2014), the annual rate-of-increase of salt-affected areas around the world is about 10%. Several factors are responsible for this rate of increase, such as (a) the weathering process of parent rocks and minerals, (b) low rainfall, (c) a high rate of evaporation from soil surfaces, (d) use of saline irrigation water and (e) unscientific farming practices (Shrivastava and Kumar, 2014). Due to salinity, a large number of streams and channels used for irrigation of farms in many countries have been in a state of jeopardy (Rasool et al., 2013). More than 75 countries around the world have problems of salinity in their productive lands (Szabolcs, 1994). The Aral Sea basin of central Asian countries (Amu-Darya and Syr-Darya River Basins), India's Indo-Gangetic Basin, Pakistan's Indus Basin, Basin of Yellow River in China, Euphrates Basin in Syria and Iraq, the Murray-Darling Basin in Australia, and the San Joaquin valley in the United States are the well-known places where land degradation has occurred in an extensive level due to salts.

According to current estimates, out of total irrigated agricultural lands, the percentage of salt affected lands for different countries are: Israel-13%, Pakistan-28%, India-27%, Australia-20%, China-15%, Iraq-50% and Egypt-30% (Stockle, 2001). In the U.S., about 12.8 million acres of agricultural land under irrigation have been affected by salinity (FAO, 2015). The major regions affected by salinity in U.S. are the Imperial Valley, the San Joaquin valley and the lower basin of Colorado River. On the west part of San Joaquin valley in California, about 4.5 million acres of irrigated farmland has been salinized (Letey, 2000). The areas affected by salinity has been increasing in a global scale as well as in US, which is creating huge economic losses by inducing crop yield loss, loss of arable farmlands, increases in the cost of farming, and loss of

land value. The central problem of this study is the potential loss of crop yield on an enormous scale in the near future, should soil salinity continue to increase at a high rate. A wide scale reduction in the yield of salt sensitive crops could be devastating to the economy of a region.

This study focuses on two major agricultural regions of Louisiana, which are dependent on two aquifers for irrigation: the MRAA (Mississippi River Alluvial Aquifer) and Chicot aquifer. Studies by LSU AgCenter (2005) and Kresse and Clark (2008) have addressed both the increase of water salinity in these aquifers and the possible impact on the irrigated agriculture of the region. However, it is difficult to find any study focusing on the potential effect of increasing salinity in agricultural production from an economic perspective. Although many studies such as those by Brownell and Eaton (1975), Adaman and Ozertan (2007), and Lambers (2003) have investigated possible solutions to the salinity problem in particular regions, very few have specifically assessed the economic viability of the potential alternatives to prevent water salinity and soil salinity. While grounded in previous studies, this paper aims to find the total economic impact of salinity on the agricultural production of the region, as well as on the economy of Louisiana as a whole. Mainly, the impact of saline soils in the yield of four major irrigated crops: rice, corn, cotton, and soybean is investigated. Similarly, this study seeks to identify alternative solutions to the salinity problem, as well as the potential economic impacts of these solutions.

1.2 Study area and current scenario

In this paper, I focus on the condition of soil salinity in Louisiana and the potential impacts of salinity on yield of major crops. Unlike the arid and semi-arid lands of the western parts of the United States, irrigated crop acres in Louisiana have not at present been badly affected by salts,

however the use of saline groundwater for irrigation has been continuously aiding in the development of soil salinity in farm lands. Out of total groundwater extracted in Louisiana, 54% is utilized for agricultural purposes while the use of surface water in farming constitutes about 5.4% of total surface water (Louisiana Ground Water Resources Commission, 2012). Salinity in Louisiana is mainly irrigation-induced as a large amount of saline groundwater extracted from underlying aquifers is used for irrigating the crops. In this study I explore the impact of saline irrigation water on crop yields in agricultural regions overlying the MRAA and Chicot aquifer where the crops studied are rice, cotton, soybean, and corn.

MRAA is a confined aquifer that links with the Mississippi River. In Louisiana, it extends from the northeastern side of the state to the mouth of Mississippi river. It is the major source of irrigation for agricultural lands of the overlying region. MRAA is the largest source of ground water in the northeastern region of Louisiana. According to the United State Geological Survey (USGS), approximately 287 Mgal (Million gallons) water per day was withdrawn from MRAA for irrigation of crops in 2011. According to the survey report of 2010 prepared by USGS, MRAA is the major source of groundwater in 26 parishes among which Tensas, Madison, Avoyelles, St. Landry, Morehouse, Franklin, and Concordia parish withdrew largest amount of groundwater in terms of volume and about 90% of withdrawn groundwater from MRAA is utilized for crop farming and fishery in these areas. Recent surveys indicate that the trend of water withdrawal from MRAA has increased rapidly over the past three decades, due to the increasing demand of water for irrigation in farmlands and other industrial purposes. According to 2012 report of Louisiana Ground Water Resources Commission, average withdrawal rate of water from MRAA has increased approximately from 280 Mgal/day in 1985 to 390 Mgal/day in 2010.

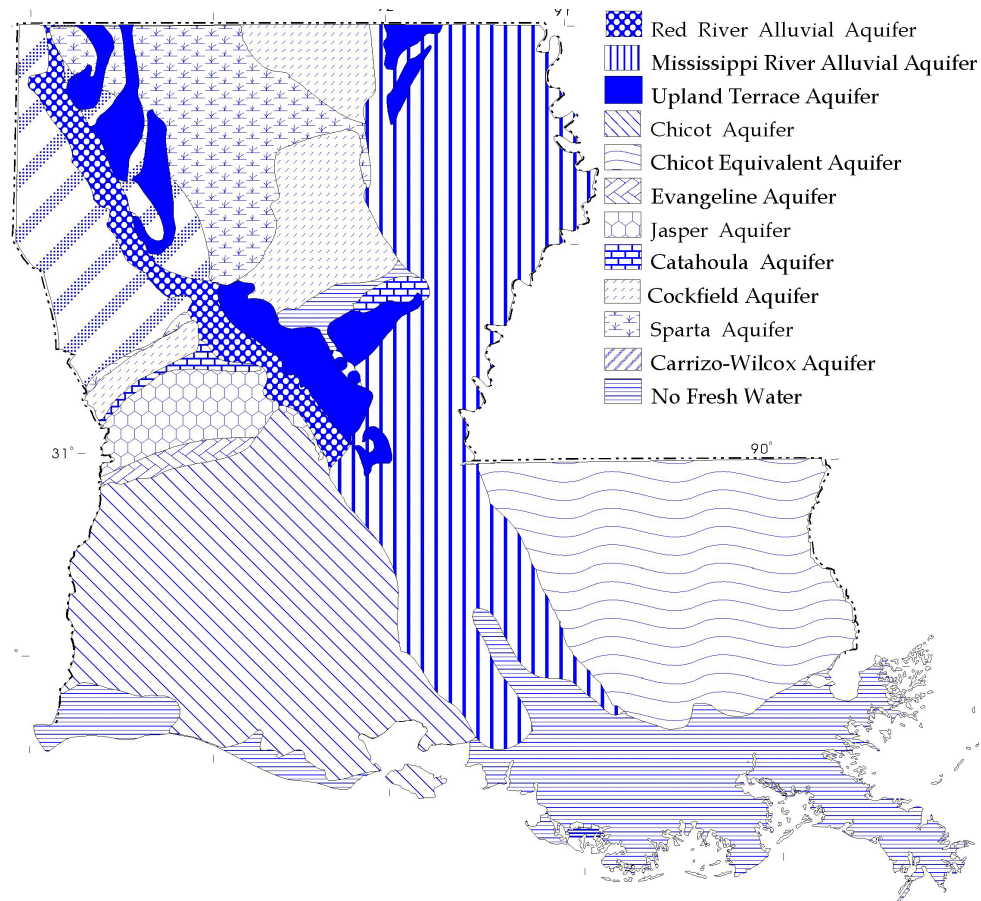


Figure 1.1. Aquifers in Louisiana¹ (Figure source: DEQ, Louisiana)

The Chicot aquifer is the major source of ground water in southwestern Louisiana and it has the highest water withdrawal rate among other aquifers of the state (USGS, 1994). Lovelace (1991) reported that the average water pumped from Chicot aquifer system was about 609 million gallons which accounted for approximately half of the total ground water extracted from all aquifers of the state during 1990. According to USDA (United States Department of

¹ Available at: http://www1.deq.louisiana.gov/portal/Portals/0/evaluation/aeps/la_aqui.gif

Agriculture) reports of 2010, approximately 343 Mgal of water was extracted per day from the Chicot aquifer. The presence of wide cones of depression indicates that there has been an over extraction of water in many areas of Chicot aquifer (DEQ, 2011). Chicot aquifer, like MRAA, is also a confined aquifer and is recharged by rainfall, intrusion of river water, and underlying aquifers. It is the source of groundwater for 15 parishes in Louisiana among which Acadia, Jefferson Davis and Calcasieu are the three major parishes withdrawing the largest volume of water (USGS, 2010). About 350 Mgal/day is withdrawn from Chicot aquifer for crop irrigation and almost all of the water is utilized for irrigating rice, as it is the only major crop grown in the region (USGS, 2010).

Both the MRAA and Chicot aquifer play a significant role in the agricultural production of Louisiana. The quality of water in these two aquifers is very important in the production of crops like rice, corn, soybeans, and cotton in the overlying parishes. Recent studies done by the USGS on these aquifers reported a gradual increase in salinity level in different regions of aquifer. If the salinity of water gradually increases, the groundwater extracted from these aquifers soon will be detrimental to crop production. Consequently, a detailed study of the extent of salinity in these aquifers, as well as a good understanding of the possible ramifications of an increased salinity in the agriculture of the irrigated regions, is necessary should the agricultural practice be made more adaptable in the future.

According to Welch and Hanor (2011), there has been an increasing trend of salinity in the MRAA in past years. Saltwater intrusion has been a major problem in the Chicot aquifer also and the salinity level has been increasing (Borrok and Broussard 2016). Rice, cotton, soybean and corn are the major crops produced in Louisiana and they contribute measurably to the

state's economy. The increasing salinity of underground water resources proves to be a major problem for the agricultural economy of the state. The parishes which utilize underground water from MRAA and Chicot for irrigation are the largest row-crop producing areas in the entire state. Since these row-crop farms almost solely rely on groundwater extracted from the two aquifers, the soil of these farms is in imminent danger of being salinized (LSU Ag Center, 2005). If proper land and water management practices are not applied, then the increased risk of irrigation induced soil salinization, will have devastating effects on the agricultural sector.

Tensas, Madison, Avoyelles, St. Landry, Morehouse, Franklin, and Concordia are the parishes which use a large amount of groundwater for irrigation from the MRAA. According to a (Stuart et al., 1994), saltwater intrusion from underlying aquifers, activities related to oil and gas, and action of seawater during ancient times which have not been flushed are the main reasons behind the increase of saltwater content in the MRAA. Recent studies by USGS suggest that, the low-lying Claiborne aquifer is the major source of salt in the northern area of MRAA. As there has been observed an increasing trend of salinity in the MRAA (Kresse and Clark, 2008), there is an increased risk of depression in the agricultural production of the region as a result of loss in crop yield when irrigated with saline water. To meet the increasing demand of water for irrigation of crops, the trend of water withdrawal from the MRAA has increased highly in the past three decades. Data from the LDEQ ASSET in 2013 shows that salinity level in wells of the MRAA was found to range from 2.7 ppm to 1,084 ppm. As irrigated crop areas are

increasing in Louisiana², dependency of farmers on groundwater for irrigation is also increasing. Salinity in the MRAA, coupled with an increased extraction of water for irrigation can produce serious impacts to the regional agricultural economy.

Similarly, agriculture in the region overlying Chicot aquifer have been facing potential danger due to the presence of salts in groundwater extracted from the aquifer. Previous studies done by Nyman (1984), Lovelace (1999) and Borrok and Broussard (2016) have reported the presence of salt water in the Chicot aquifer. Borrok and Broussard (2016), found increasing trend of salinity in southwestern part of the aquifer. The upward trend of salinity in the Chicot aquifer is due to intrusion of saltwater from naturally occurring salt domes in the vicinity of the Gulf of Mexico (Louisiana Ground Water Resources Commission, 2012). Given that rice is the major crop of this region and also a salt sensitive crop, progressive development of salinity in the Chicot aquifer could be a potential problem for rice production. Figure 1.2 shows the contour maps of salinity level in groundwater obtained from 20 sampled wells in Chicot aquifer. The figure shows salinity value obtained from these wells in 1996, 2002, 2005, 2008, 2011, and 2014. We can see that areas closer to the coast have the highest salinity which reflects the impact of salt water encroachment. The zone representing highest salinity (0.5-2 ppt) is seen to have lowest extent in 1996 and 2002 but has been increasing over time, as can be seen in the

² According a report by Olivia J. McClure published in LSU AgCenter in 2015, irrigated crop acres in Louisiana have increased from 702,000 in 1974 to 1.2 million in 2013.

figure. The zone with highest salinity reached its greatest bound in 2011, when a severe drought occurred in the region (Lal et al., 2012; Tadesse et al., 2015). According to Guidry and Pruitt (2012), the drought in 2011 severely affected the crop production in Louisiana resulting in a loss of \$436 million. Increase in water withdrawal from the Chicot aquifer in response to the drought in 2011 is reflected in the figure by the northward movement of the high salinity zone, reaching the highest coverage in 2011.

Similarly, figure 1.3 shows the distribution of salt concentration in the MRAA for two different periods of time. The figure compares the salt concentration in the MRAA in 2004 and 2016, thereby showing how the concentration of salt having increased in the MRAA within the span of time. From the figure, one can see that the region with high salt concentration, denoted by the dark green spots, was only limited to a small area within the MRAA in 2004. By 2016, the high salt concentration region had already spread to a large area and, in the region containing high amount of salts in 2004, the salt concentration can be found to have increased even more, which is represented by the darker yellow and red spots on the diagram. Figure 1.3 clearly shows that salt concentration in MRAA ranges from 615 ppm to more than 4000 ppm. The presence of salts in such a high concentration in the MRAA can be a serious problem for agriculture of that region given that major irrigated crops grown in the region such as rice, corn, and soybeans, depend on groundwater for irrigation.

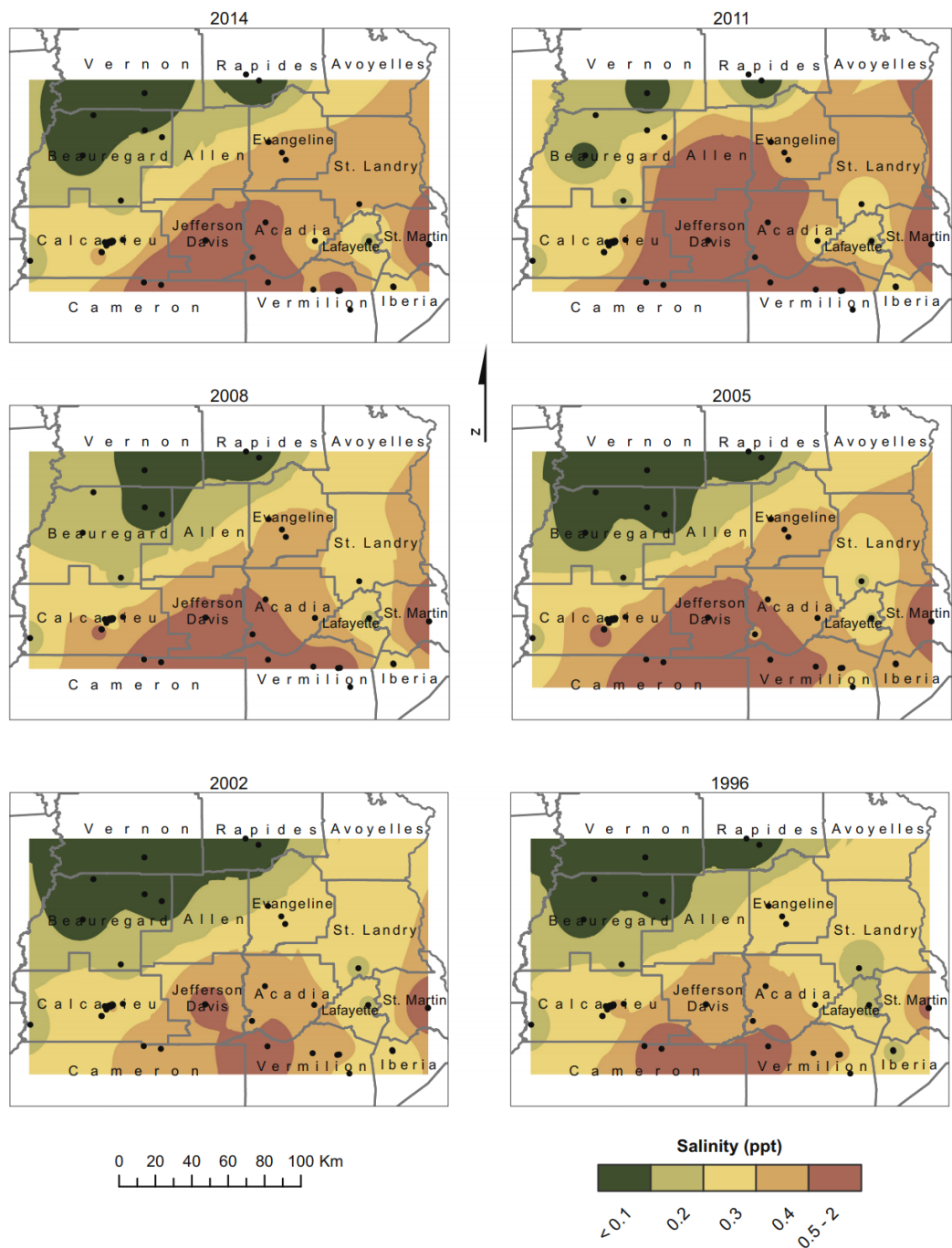


Figure 1. 2. Contour map showing salinity level for groundwater samples collected in 2014, 2011, 2008, 2005, 2002, and 1996 from Chicot aquifer. (Figure source: Borrok and Broussard, 2016)

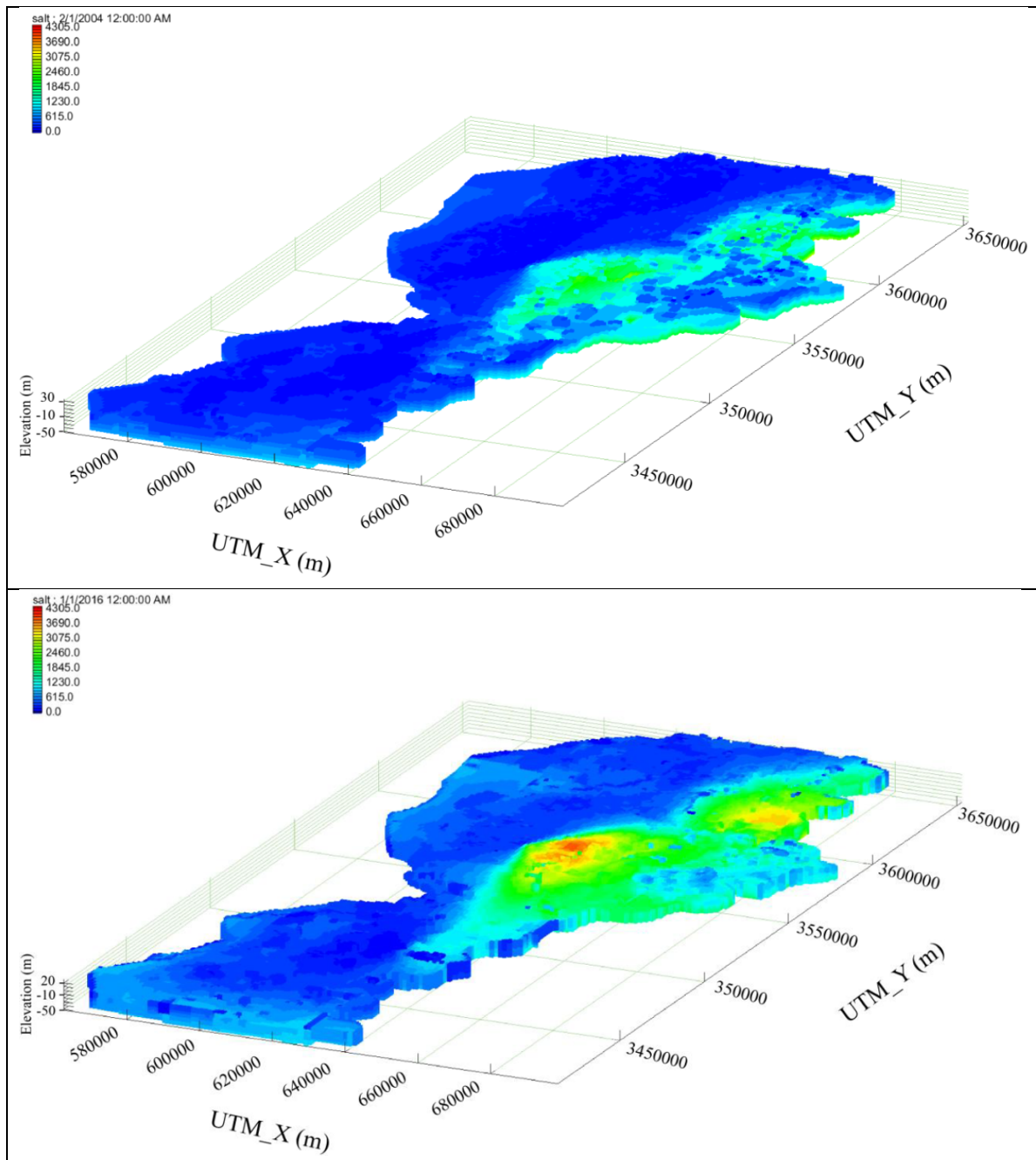


Figure 1. 3. The distribution of salt concentration in MRAA in January 2004 (upper) and January 2016 (lower). (Figure source: Ramazan's thesis, 2018)

Dealing with salinity raises the need to engage with a large body of literature attached to several disciplines but the most discussed topic is land and agriculture and the impacts that salinity has on them. The subject of Agronomy strives to provide insights about bio-physical

impacts of salinity on crops (Wallender and Tanji, 2011). Knowledge about effect of abiotic stresses caused by salinity on plant and employing of breeding techniques to make crops salt tolerant or improve their tolerance level is provided by other areas of sciences such as plant physiology, genetics and biochemistry (Foolad, 2007; Jewell et al., 2010). Disciplines like hydrological sciences helps to understand the underlying processes of transport of salt and its accumulation in soils under the influence of natural and human factors (Schoups et al., 2005; Suweis et al., 2010) and the possible effects of salinity on environment (Pitman and Lauchli, 2002). This paper is mainly motivated to address the encroaching problem of soil salinity from an economic standpoint. Acquiring knowledge and insights generated by other disciplines, blending this information into suitable models and analyzing agricultural practices and the possible alternatives from an economic perspective, pointing out the appropriate technologies and plans to gain optimum efficacy; testing these strategies in the market to ascertain possible damages, and finally building policies to ameliorate soil salinity impacts on agricultural crops and water resources is the work of economists on this issue (Dinar and Zilberman, 2012; Knapp, 1999). In this paper, I seek to excavate the economic impacts of soil salinity on crop yield and on whole farm economy, explore the possible solutions for the salinity problem under different crop selection and management practices, as well as evaluate the economic aftermaths of these management practices.

1.3 Research Objectives

The general objectives of this study are presented below:

1. Identify the loss in yield of crops due to soil salinization and estimate the economic contribution on the regional and state economy.
2. Calculate the economic impacts of an alternative solution for the salinity problem under
 - a) the adoption of more salt-tolerant crop varieties, and
 - b) the change in cropping system to prevent salinity induced yield loss.

Before continuing to the next chapter, I will provide a brief outline of what this study explores in the upcoming chapters. In chapter 2, I will present a literature review of past studies related to soil salinity, its potential effect on the yield of crops and the economics related to its impact on crop yield. Similarly, I will create scenarios regarding the future salinity level in the MRAA and Chicot aquifers and use the predicted salinity values to estimate yield loss in three major irrigated crops: rice, corn and soybeans. In chapter 4, I will use IMPLAN to estimate the potential economic impact of salinity induced crop yield on the regional and state economy. In addition to that, I will also explore the economic impacts of adopting alternative solutions to the salinity problem. Chapter 5 presents the summary and conclusion of this study along with some limitations.

Chapter 2. Literature Review

2.1 Salinization of soil

There is a large volume of literature that explores different aspects of soil salinization. Schofield et al (2001) defined soil salinization as a salt accumulation process within soil layers which can cause soil degradation. Soil salinization occurs when water-soluble salts accumulate to a certain level in the soil which eventually becomes detrimental for crop production. Similarly, many other studies have explored the process of soil salinization and the possible sources from which salt can accumulate in soil. Vengosh (2003) explained that in low-lying lands, soluble salt accumulates within soil layers when the rate of evaporation from soil surpasses the precipitation rate which prevents the leaching of salts from the upper soil layers. Vengosh (2003) also shed light on the concept of primary and secondary salinization of soil: primary salinization of the soil occurs naturally in regions with arid and semi-arid climate, while secondary salinization generally occurs as a result of human intervention in agricultural lands. Primary salinization is determined by climatic, topographic and the geological makeup of a region (Schofield et al., 2001) while irrigation is one of the main causes of secondary salinization (Spoor, 1998). The largest impact of secondary salinization of the soil can be seen on agricultural lands which are irrigated and about 25 million ha of land worldwide becomes unfit for agriculture annually due to salinity (Szabolcs, 1987).

This study centers on the process of secondary salinization of the soil induced by irrigation. A review of past studies draws an understanding of how salt affected irrigation water withdrawn from the MRAA and Chicot aquifer, can be the main factor causing soil salinization in crop fields of the region. Brouwer et al. (1985) explained the process of irrigation induced soil

salinization. According to their findings, after irrigation of crops, the salt affected water is used by crops or evaporates directly to the air from the soil surface and in this process only the salt contained in the water is left behind in the soil which continues to accumulate with time to cause secondary salinization. Furthermore, they explain that secondary soil salinization can also occur due to the presence of shallow salty groundwater level beneath lands where crops are grown. They describe how shallow groundwater level coupled with poor drainage system can cause soil salinity. Their study explains that in absence of proper drainage systems, the water table rises with irrigation which causes the salt affected groundwater to reach the upper layers of soil eventually causing accumulation of salts in plant root zones.

2.2 Impact of salinity on crop yield

A large body of literature exists that has investigated the effect of salt on the growth and development of crops as well as their yield. Some of the studies have explored how salt disturbs the physio-chemical functioning of cells which can eventually lead to death of plant cells while other studies have focused on how the effect of salt can be different in various stages of crop growth. Jones and Marshall (1992), found that the osmotic potential of soil solution is increased due to the rise in the salinity level of the soil to which the growth of crop is adversely affected and yield begins to decrease. Ayers and Westcot (1985) maintain that the symptoms which appear in plants growing in the soil with high salinity are similar to those of plants affected by extreme drought. Hence, soil salinity and wilting (caused by excessive drought) both show similar kind of deleterious effects on crop growth. Munns and Gilliham (2015) explain the loss of yield in crops due to salinity by using the energy concept. According to them, salinity hampers the basic physiological processes in plants which are vital for producing energy and

increasing biomass. High salinity in the root zone disturbs the opening and closing pattern of stomata and damages basic photosynthetic machinery such that the plant ceases to grow and eventually yield is reduced. According to most studies done, it is understood that increases in salt content in the soil solution seriously disturbs the proper functioning of roots and other organs of the plant which in turn results in poor growth and development. This eventually leads to a decrease in crop yields. Understanding only the basic mechanism relating to effect of salt on crops will be sufficient for our study as I focus more on the economic aspect of salinity rather than the physiological aspect.

2.3 Determining the yield loss in crop due to salinity

There is a growing body of literature analyzing the impacts of soil salinity in agriculture. To date, I can find many studies which have strived to estimate the extent of damage occurring in crop production due to salinity by understanding basic interactions between the soil salinity level and the crop growth pattern. Salt accumulation in the soil becomes problematic when a significant amount of salt deposits in the root zone of crops and hinders the proper growth of plants causing a reduction in yield. According to Qiu et al. (2017), a decrease in yield of plants due to effect of salinity is equivalently related with the decrease in ET (evapotranspiration) and several studies have proved by using a linear response model that increases in salinity hinders the water uptake of plants thereby decreasing the ET. Similarly, numerous studies have attempted to describe the response of crop yield to saline soil conditions. Bernstein (1980) used discrete point tables to assess the relationship between salinity and crop yield. Hand fitted crop yield response functions were used by U.S. Salinity Laboratory (1954) and Yaron and Olian (1973) to describe the process of the salt effect on crops. Methods utilizing linear models and

OLS (ordinary least squares) regression was used by Yaron et al (1972), Nouri (1970) and Shalhavet and Bernstein (1968) to fit the yield response function for salinity.

The findings of Maas and Hoffman (1977) were highly successful in accurately evaluating the response of crop yield to increasing levels of soil salinity. Their study adopted a two line segment response curve to describe the behavior of crop yields growing in saline conditions. The response curve shows two line segments, one line with a zero slope representing the tolerance behavior of a crop, and the other line displaying a negative slope. The response curve depicted the pattern of yield reduction in a crop with increasing salinity. By this means, Maas and Hoffman established a “threshold” of salinity in their function which was the point of intersection between the two lines. This threshold was designated as the maximum soil salt concentration up to which the yield of crops was not affected. This “threshold” was the maximum permissible level of salinity in the soil. According to the study, should salinity in the soil be below the threshold level, no changes in crop yield would be observed, as shown by the line with zero slope. However, as the salt concentration in soil increases to surpass the threshold level then the crop yield will gradually decrease in a linear fashion, which could be explained by the negatively sloped line. The following mathematical equation was derived to explain the interaction between relative crop yield and level of salinity of the soil in the root zone (measured in EC) which is:

$$Relative\ yield = 100 - B (ECe - C')$$

where, C' is threshold salinity expressed in dS/m; ECe is the mean electrical conductivity of soil extract in root zone, and B is the slope of the yield-salinity curve at ECe values greater than C' .

Several studies such as those accomplished by Feinerman and Yaron (1982), Maas and Grattan (1999) among others have used this yield response function given by Mass and Hoffman (1977) to estimate the yield loss in different crops under saline soil conditions. Tanji (1990) asserted that the concept of two stage linear interaction between crop yield and soil salinity proposed by Maas and Hoffman (1977), gives a convincing idea in regard to the effects of salinity on crop yield. Similarly, Maas and Grattan (1999) did an extensive study to gain more insights on how different crops respond to salinity and attempted to estimate the degree of damage on yield due to salinity along with exploring possible strategies to regain the lost yield by keeping salinity in check. Keeping in accord with the earlier idea on threshold salinity, their study introduced the concept that this threshold level is directly affected by the inherent salt tolerating capacity of a given crop species, which could be influenced by the interaction between salts and various edaphic, irrigation and climatic conditions. Their study maintained that even though various unfavorable environmental conditions might reduce crop yield, their effect on salt tolerance of crop could be constructive or destructive depending upon crop type and variety. Hence, while predicting the yield loss due to salinity, it was deemed important to consider other environmental factors that could possibly influence the salt effect on plant.

In the study conducted by Maas and Grattan (1999), regarding the influence of several crop environment parameters on their response to salinity, different level of absolute salt tolerance were observed in the same crop when they were grown on different soil and climatic conditions. They noticed that a specific crop may appear to have varying salt tolerance levels when subjected to optimal and suboptimal conditions and the original level of tolerance could only be ascertained in the form of a relative tolerance level, which the study evaluated by

plotting the relative yield against the salinity level in both adequate and limiting farm conditions. They came up with three findings about the salt tolerance behavior of crops when grown in varying farm conditions. First, if the yield of a crop is very low due to suboptimal farm conditions, e.g. low fertility of soil, the crop may appear more salt tolerant than it would be under optimum farming conditions because an adequately fertile soil can have a greater effect on absolute crop yield than salinity. Second, if the decrease in absolute crop yield is the same in both adequate and limiting farm conditions, the crop may seem to be less tolerant under the limiting condition. Third, if the absolute yield of a crop decreases by the same percentage in both optimal and suboptimal conditions, there would be no variation in the relative salt tolerance level. Using the slope elements and threshold value of soil salinity provided by Maas and Grattan (1999), Houk et al. (2006) also attempted to model the effect of soil salinity on different crops. They found that different crops responded in different ways to increases in salinity and the threshold level varied greatly between the studied crops depending on their sensitivity and tolerance to salts.

Several analytical methods have been tested to truly assess the economic losses incurred due to the effect of salinity on agriculture, whether it may be due to yield loss of crops or due to increase in costs for managing salt affected lands and irrigation water. For example, Hussain and Young (1985) and Joshi (1987) used a production function approach to assess the loss which occurred on crop farms due to salinization of the soil, but they both used different variables for estimating the losses. The variables used by the former was EC (electrical conductivity) while the latter assigned a dummy variable. Later, Joshi and Jha (1992) also made use of an alternative production function approach to evaluate the impacts of salinity at the

farm level in terms of crop yield and use of farm resources. Joshi and Jha (1992) made a comparison between normal and salinity affected land in terms of total yield. The observed change in gross output between these lands was divided into: change due to salinity and change due to the difference in management of farm inputs. To make the analysis more general, production functions were separately assessed for different soil types. The crops whose yield was studied under saline soil conditions were paddy, wheat, maize, barley, pea, mustard and other pulses. It was observed that yield of paddy and wheat decreased by 51% and 56% respectively. Barley was found to be the most tolerant among all other crops with yield losses of only 18%. Furthermore, net income generated from farms where HYV (high yield varieties) were cultivated was found to fall by about 87% due to effect of saline soil. The findings of this study indicated that, farming in salt affected lands resulted in measurable losses of yield of different crops except for salt tolerant crops like barley.

Similarly, Mendoza (2004) estimated the damages to the agricultural sector due to salinity in Juarez Valley, Mexico when water from Rio Grande River, groundwater from Hueco Bolson area and Ciudad Juarez wastewater was used for irrigation of crops. He tried to assess the reduction in yield of different crops due to salinity by using the crop yield response function used by Maas and Grattan (1999) together with the total losses occurred in the whole farm scenario due to this loss in crop yield. He calculated the leaching fraction of irrigation water and utilized it to estimate new value of Electrical Conductivity for the root zone soil, which he used in the response function to get the reduction in yield. In his study, he calculated the decrease in yield of two irrigated crops (cotton and alfalfa) and the total loss in yield was estimated, which he multiplied by the average market price of those crops to get the total loss in dollars. He

found that salinization of cropland due to supply of irrigation water from groundwater and wastewater were responsible for loss in yield where the groundwater source caused a 15% reduction in alfalfa yield resulting in a loss of \$6,144,707 whereas, irrigation by wastewater caused a 25% reduction in yield resulting in a loss of \$9,223,936.

Quantitative evaluation of the loss incurred due to salinity has mostly been limited to productive land lost due to excessive saline conditions or crop yield losses (Umali, 1993). There lacks a study which quantifies the total farm value lost due to salinity induced yield loss in crops and the economic impact of crop yield loss on the whole crop production region. My thesis aims to add to the previous literature on economics of salinity by estimating the extent of damage of soil salinity in three major crops of Louisiana: rice, soybean, and corn. For this study, I use the yield response function developed by Maas and Hoffman (1977) as well as the threshold salinity and slope value of crops provided by Maas and Grattan (1999) to estimate the salinity induced crop yield loss. Furthermore, this study aims to estimate the possible economic impact of salinity induced crop yield loss in a broad economic frame.

2.4 Overcoming salinity problem

Several studies have provided alternative techniques and management practices to reduce the effect of salinity on crop yield. According to Provin and Pitt (2001), improving the drainage condition of soil, periodic leaching, reducing rate of evaporation, and applying different chemicals in soil to neutralize the effect of salt are some of the effective techniques to reduce the salt concentration in soil. Unfortunately, these techniques cannot be applied in all kind of soil and crop conditions. Under some conditions, increases of salt content in the soil is inevitable due to the presence of salt in irrigation water. Under those conditions, I have to

make changes in the cropping pattern of the land which can cope with high salt conditions or grow crops which are salt tolerant or introduce different varieties of the same crop which is more tolerant to saline soil conditions. Salt tolerant crops are engineered to flourish in high salt conditions and require less investment or management. Adopting salt tolerant crops on farm lands suffering with high salt content can be very effective in utilizing the farmland by producing crops without spending on other costly management practices like drainage construction or leaching.

Enhancing the salt tolerating capacity in crop cultivars by exploiting their genetic variability can be the most cost effective solution to the problem of soil salinity in agriculture. According to Epstein and Rains (1987), development of crop cultivars with high salt tolerance has been regarded as the most economically efficient strategy to deal with the widespread salinity problem in agricultural lands. International Rice Research Institute (IRRI) has developed several salt resistant rice varieties: IRRI-12, IRRI-13, IRRI-24, IRRI-25, IRRI-26, and IRRI-28 but they are yet to be tested for their efficiency in varying soil and climatic conditions. Similarly, plant breeders and researchers are continuously working to develop improved varieties of soybeans and corn, which are salt tolerant, so that they can be adopted in the commercial farming system when salinity conditions of the soil start to become unfavorable for maintaining crop yield.

Chapter 3. Estimating the Potential Yield Loss Due to Salinity

3.1 Trend of increase in salinity in the Mississippi River Alluvial Aquifer and Chicot Aquifer

A significant rise in the salinity level has been observed in different regions of the MRAA and Chicot aquifer over the last few decades. Stuart et al. (1994) found that saltwater intrusion from underlying aquifers is one of the main reasons behind the buildup of salt water content in the MRAA. According to Lovelace (1999), the low-lying Claiborne aquifer has been found to be the major source of salt in northern regions of the MRAA. The level of chlorine in the wells installed for studying water quality in the MRAA by LDEQ ASSET has been found to have up to 602 mg/l of chlorine. In a study conducted by LDEQ ASSET program³, the average salinity in 23 wells in different locations in the MRAA showed an increasing trend from 1996 to 2011. Similarly, the elevated salinity problem has been encountered in several regions of the Chicot aquifer. Nyman (1984), Lovelace (1999) and Borrok and Broussard (2016) have found the presence of salt water in the aquifer with an increasing trend. Welch and Hanor (2011) explained that intrusion of saltwater from naturally occurring salt domes close to aquifer is the principle factor responsible for increased salinity in the MRAA. According to Lovelace (1999), around the beginning of the century, the high rate of pumping water from the aquifer system for rice farming in the area has substantially increased the potential for saltwater intrusion as

³ LDEQ ASSET program is a program conducted by Louisiana Department of Environmental Quality (LDEQ) for Aquifer Sampling and Assessment (ASSET)

heavy water withdrawal created a cone of depression in the aquifer causing salt water from other places to flow inside.

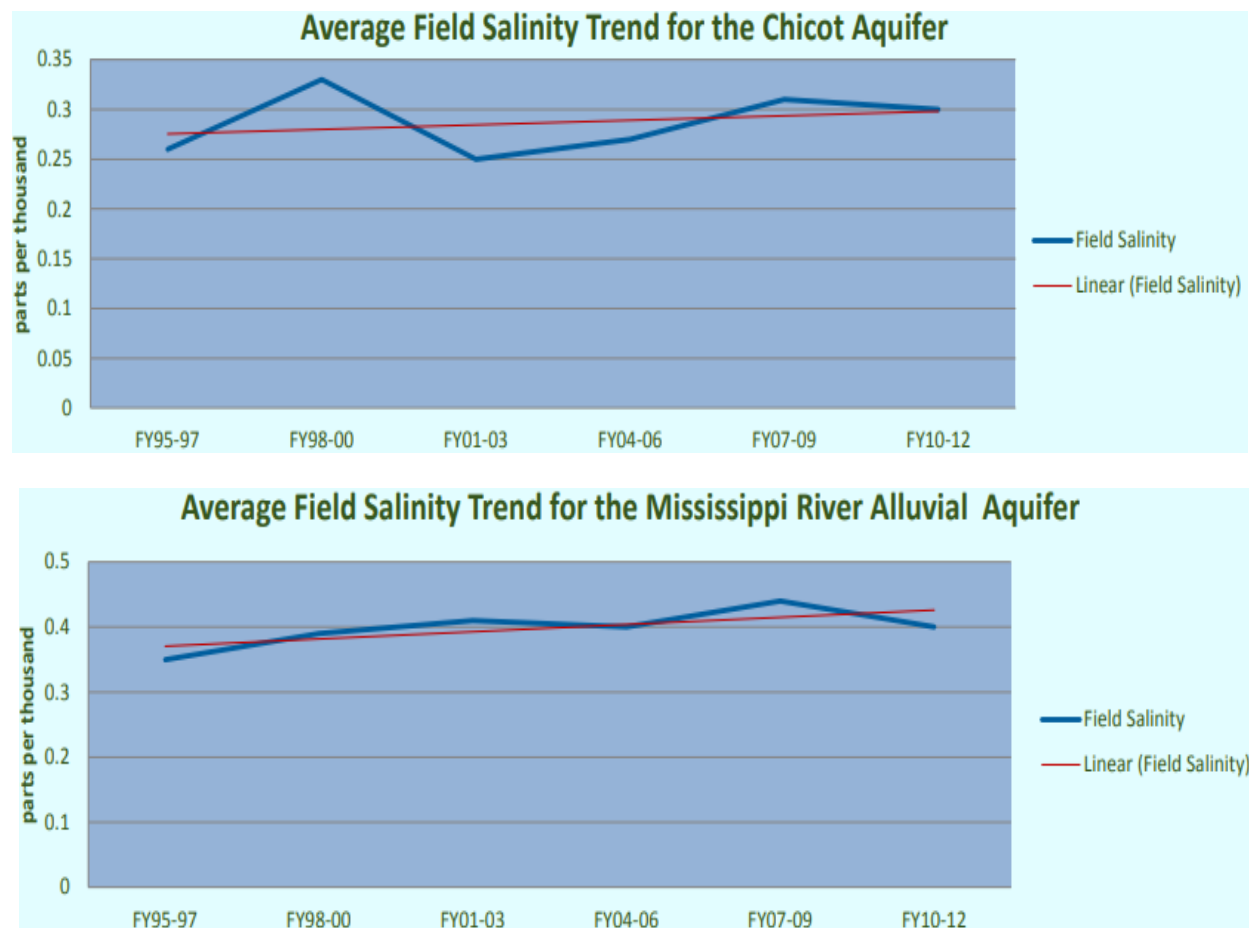


Figure 3. 1. Average field salinity trend for the Mississippi River Alluvial Aquifer and the Chicot Aquifer (Source: Louisiana Department of Environmental Quality, Triennial Report 2012)

The triennial report of LDEQ (2012) showed that the average salinity level in groundwater has been increasing for both the MRAA and Chicot aquifers (see figure 3.1). In this section of my thesis, I estimate the possible economic effects of increasing salinity levels in the MRAA and Chicot aquifers on the agricultural production of the whole region. The region constitutes all agricultural areas which directly utilize water for irrigation from these aquifers.

Given the present trend of rises in the salinity level in the two aquifers, I predict the salinity level in the near future and the potential loss in crop yield due to salinity.

3.2 Data

Data used for this study were obtained from the USGS database of chloride monitoring wells in different parishes overlying the MRAA and Chicot aquifers. Data from 54 chloride monitoring wells installed by USGS for water quality study were also utilized; however only a few wells have complete information regarding the chloride concentration of water, recorded from the 1970's to the present. Similarly, I use the data of chloride content and average field salinity recorded by LDEQ ASSET from 23 wells situated in different region of these aquifers. In addition, this study utilizes the findings of Borrok and Broussard (2016), regarding the present condition of salinity in Chicot aquifer and predict the salinity for future scenario. Figure 3.2 shows the locations of chloride monitoring wells installed in the regions overlying the MRAA and Chicot aquifers along with other regions. The green dots show the location of wells installed before 2013 while the red dots show the location of newly installed wells. Data from USDA/NASS (2017) is used to obtain yield information of crops along with their market price in different parishes of Louisiana. In this study, average value of crop yield and prices are used. Threshold salinity and yield slope values of all the crops under study are used from the findings of Maas and Grattan (1999).

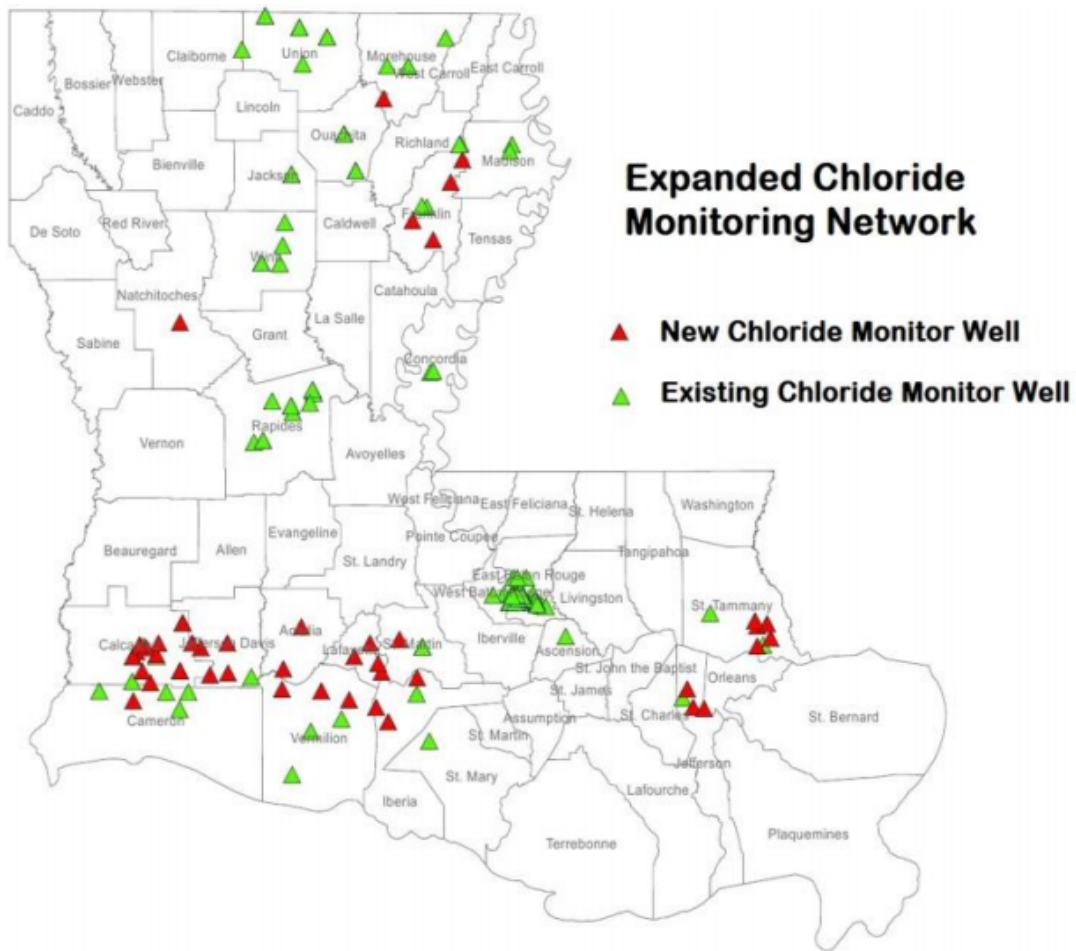


Figure 3. 2. USGS chloride monitoring wells in MRAA and Chicot aquifer (Figure source: Louisiana Groundwater Commission, 2016)

3.3 Method and assumptions

In this study, I use the threshold salinity model of Mass and Hoffman (1977) to predict the potential loss in crop yield due to salinity. Similarly, I use the salt tolerance data provided by Mass and Grattan for the calculation of yield losses for rice, soybean, and corn as well for other salt tolerant crops like cotton, sorghum and wheat. The data contains the threshold salinity value of crops and slope value (percent loss in crop yield with one unit rise in salinity above the threshold value). The salinity is expressed in the form of EC where EC_e = root zone salinity and

EC_w = salinity of irrigation water. The threshold salinity model can be mathematically expressed as

$$Relative\ yield = 100 - B (EC_e - C')$$

where, C' is threshold salinity expressed in dS/m (desi Siemens per meter); EC_e is the mean electrical conductivity of soil extract in root zone; and B is the slope of the yield-salinity curve at EC_e values greater than C' .

I use the value of chloride⁴ content of water measured in ppm to estimate the salinity of irrigation water (EC_w) in dS/m⁵. In their study, Maas and Hoffman (1977), used the value of salinity present in crop root zone to build a linear relation between root zone salinity and yield of crops. Therefore, in this study I calculate the salinity of the root zone when irrigated by saline water to find out the response of crop to salinity level. Root zone or soil salinity (EC_e) is calculated from irrigation water salinity (EC_w) by using a simple formula given below.

$$EC_e = 1.5EC_w$$

The above relation between water salinity and root zone soil salinity holds when we assume that between 15 and 20 % of irrigation water is lost through leaching and water use patterns from upper to lower quarter of the root zone in 40-30-20-10.

⁴ To convert chloride concentration to salinity, use the formula salinity (ppt) = 0.0018066 5 Cl⁻ (mg/L) (Source: <http://soiltesting.tamu.edu/publications/B-1667.pdf>). See also <http://www.fao.org/docrep/r4082e/r4082e08.htm>

⁵ 1 dS/m = 1 mmhos/cm = 640 ppm

In this study, IMPLAN software is used to assess the economic impacts created by the loss of crop yield due to salinity. IMPLAN is an input-output based model that contains the detailed information about all the economic activities at the state and county level for the entire U.S. This model allows one to determine the economic impact of crop (rice, corn and soybean) production on the local as well as the state economy along with the details of negative economic changes when there is significant reduction in crop yield at a given time. Similarly, economic changes created due to a change in cropping system is also analyzed through IMPLAN.

Assumptions

While using the data from USGS wells, there was a major problem. In contrast to the general understanding validated by several sources that salinity is increasing in MRAA and Chicot aquifers, more than half of the USGS chloride monitoring wells showed a decreasing trend of chloride concentration. Data of chloride content of these wells is given from the 1970s to the present where it can be seen that chloride concentration of several wells showed gradual decline (see appendix 1). According to Lovelace (1999), the observed decrease in chloride content in upper sand of the Chicot aquifer may be due to the elevated recharge of water from the Atchafalaya River or other nearby surface water sources. After consulting with some colleagues from the civil engineering department, I found that another reason for the observed fluctuation in chloride concentration in groundwater wells might also be due to the change in direction of movement of the salt water plume induced by the change in water pumping rates in different places. Improper methods for collecting water samples from these monitoring wells can also be another reason for these unusual level of chloride content in groundwater. As

Lovelace (1999) describes that water from other areas of aquifer tend to flow toward the regions where extraction of water is a maximum, which can be seen in major rice growing areas of regions overlying Chicot aquifer and the cone of depression created due to over extraction of water could cause saltwater plume to enter the depression area. Ramazan (2018) finds that the salt concentration in most of the observation wells did not show any linear pattern of rise or fall in salinity level but rather they found it fluctuates with time. He concluded that the model which he used for assessing distribution of salt concentration in the MRAA aquifer shows elusive trends of salinity observations during the process of calibration.

In contrast to the USGS well data, several other findings have clearly indicated that salinity level has been rising steadily in many regions of the MRAA and Chicot aquifers. For example, findings of Ramazan (2018) show an increasing trend of salinity in the MRAA. Similarly, Borrok and Broussard (2016) showed that salinity in the Chicot aquifer is increasing. Based on the findings of all these studies, it can be inferred that in the coming decades salinity will increase significantly in the MRAA and Chicot aquifers.

In order to identify and adopt proper cropping practices in the coming decades, a clear picture of the potential consequences of these salinity conditions must be understood so that important decisions related to cropping systems as well as changes required to make the crop production more sustainable even in high saline conditions. However, the lack of reliability in salinity trend data obtained from groundwater wells hinders the prediction of future salinity conditions from available data. Therefore, in this study I have attempted to estimate the future salinity conditions by making some assumptions based on the findings of several studies.

I assume three different scenarios depicting three potential rates of increase in salinity. The first two scenarios assumed are the lower and upper limits of the rate of salinity rise which can be seen in the data obtained from USGS chloride monitoring wells. However, the assumption of the third scenario reflects the extreme condition and is only considered in this study to reflect the possible worst case scenario of salinity rise.

1. Low slope condition: With an adoption of optimal farming practice, coupled with restriction of over-extraction of groundwater for irrigation and other favorable hydro-geological conditions, it is assumed that salinity will increase at a very low rate. In this condition, salinity increases at a rate of 5 ppm per year.
2. Medium slope condition: Without adoption of efficient farming practices and the water pumping rates affiliated with other stable hydro-geological conditions, it is assumed that salinity will keep on increasing with a medium slope. In this condition, salinity increases at a rate of 20 ppm per year.
3. High slope condition: Under extreme drought conditions, unrestricted extraction of groundwater for irrigation, and unfavorable hydro-geological processes, it is assumed that salinity will increase at a very high rate. In this condition, salinity increases at a rate of 50 ppm per year.

This study then uses these three assumptions above to estimate the salinity level of two aquifers after 10, 20 and 30 years. Three different slope conditions utilizing three different time periods gives us nine different scenarios to explore. The estimated salinity value is then used to predict the yield loss of crops in respective scenarios.

3.4 Results

Table 3.1 shows the threshold salinity and slope value for rice, corn and soybeans as provided by Maas and Grattan (1999). These values for crops are used to estimate the yield loss in respective crops for a given level of salinity. Cotton is also a major irrigated crop grown in the MRAA region, but I exclude cotton from this study because the focus of this study is on salt sensitive crops and cotton is less sensitive to increasing salinity levels.

Table 3. 1. Threshold salinity and slope value of rice, corn and soybean

Crops	Threshold Salinity Level (TSL)	Slope (%)
Rice	3.0	12
Corn	1.7	12
Soybean	5.0	20

(Note: TSL = Maximum salinity level up to which there is no effect of salinity on yield and it is expressed in mmhos/cm; Slope = Percentage loss in crop yield per unit increase in salinity when salinity level surpasses TSL)

Source: Maas and Grattan (1999)

Table 3.2 contains the current average field salinity and predicted level of salinity in crop growing areas overlying the MRAA and Chicot aquifer after 10 years, 20 years and 30 years under three different scenarios of salinity rise. The salinity level in water is expressed in parts per thousand (ppt). Then using this ppt. value, soil salinity is estimated which is expressed in millimhos per centimeter (mmhos cm^{-1}). By taking the average of salinity values obtained from different studies in the respective aquifer, the present value of average root zone soil salinity in the MRAA and Chicot is calculated.

The abbreviations L, M and H denote low, medium and high rates of salinity increase in these aquifers respectively. In the respective columns, there is the value of predicted salinity after 10, 20 and 30 years. Soil salinity is estimated and expressed in mmhos/cm for the ease of

calculating the predicted yield loss in crops by using threshold salinity model provided by Maas and Hoffman (1977).

Table 3. 2. Average predicted soil salinity in regions overlying two aquifers in the future

Aquifer	Average Root Zone Soil Salinity										
	Unit of Salinity	Now	In 10 years			In 20 years			In 30 years		
			L	M	H	L	M	H	L	M	H
Chicot	ppt	1.2	1.25	1.4	1.7	1.3	1.6	2.2	1.35	1.8	2.7
	mmhoscm ⁻¹	2.8	2.9	3.3	4.0	3.0	3.8	5.2	3.2	4.2	6.3
MRAA	ppt	1.4	1.45	1.6	1.9	1.5	1.8	2.4	1.55	2.0	2.9
	mmhoscm ⁻¹	3.3	3.4	3.8	4.5	3.5	4.2	5.6	3.6	4.7	6.8

(Note: L = Salinity rises at a low rate, M = Salinity rises at a medium rate, H = Salinity rises at a high rate, ppt = Parts per thousand, 1 ppt = 1000 ppm or parts per million)

The result from Table 3.1 is used to predict the loss of yield in rice, corn and soybean in the future due to the increased salinity of groundwater. Table 3.3 shows the predicted yield of crops 10, 20 and 30 years from now when subject to different levels of salinity, supposing that there is no change in yield of crops, no technological improvements, no adoption of drought tolerant crop varieties, and no change in cultivation as well as irrigation practices. The yield of crops shown in Table 3.3 is their average yield in irrigated acres of Louisiana. Although corn and soybean are measured in bushels, I have converted bushels to cwt for the ease of calculation. Yield loss results of Table 3.3 are produced by using the threshold salinity model developed by Maas and Hoffman (1977).

Let's look at one of the scenario where I have estimated the yield loss in rice in the Chicot region in the 20th year, when salinity rises with a high rate. The threshold value of rice is 3 mmhos/cm and the slope is 12. This means that for every unit rise of salinity beyond the threshold value, the yield of rice decreases by 12%. By using the threshold equation provided

by Maas and Hoffman (1977), we can find the relative yield of a crop for any salinity level. In the particular scenario I am explaining, the value of salinity is 5.2 mmhos/cm (see Table 3.2). When I put the threshold salinity value or C' (3.0), slope value or B (12), and soil salinity value or EC_e (5.2) into that salinity equation, I find that the relative yield is 73.6. This means that 73.6% of 67.1 cwt/acre (current yield) is 49.4 cwt/acre, as can be seen in Table 3.3.

From Table 3.3, it can be seen that a substantial loss in yield of crops due to the increase in soil salinity in the future. For instance, 20 years from now, the yield of rice in regions overlying the Chicot aquifer is predicted to decrease by 12% if the salinity of water increases at a rate of 20 ppm per year. Yield loss of about 8 cwt/acre will have a disastrous effect on the agriculture of the region. Results in table 3.3 show that even a low rate of increase in salinity can cause a significant loss in corn yield. According to the prediction, in 10 years, corn yield will decrease by about 13 cwt/acre even if the rate of increase in salinity is very low, which is 5 ppm per year. If salinity was to increase at a high rate, yield loss in corn would be completely devastating when I look at the condition after 2 or 3 decades. The results of Table 3.3 are used to estimate the lost revenues due to salinity induced yield loss. IMPLAN then uses these estimated numbers as the major final demand input for the impact analysis of crop yield loss on the region or the state.

Table 3. 3. Predicted loss in irrigated crop yield due to salinity under constant yield conditions for different scenarios

Aquifer	Crops	Crop yield (cwt/acre) and yield loss in %									
		Now	10 th year			20 th year			30 th year		
			L	M	H	L	M	H	L	M	H
Chicot	Rice	67.1	67.1	64.7	59.0	67.1	60.7	49.4	65.5	57.4	40.5
			0%	3.6%	12%	0%	9.6%	26.4%	2.4%	14.4%	39.6%
MRAA	Rice	67.1	63.9	60.7	18.0	63.1	57.4	46.2	62.3	53.4	36.5
			4.8%	9.6%	55%	6%	14.4%	31.2%	7.2%	20.4%	45.6%
	Corn	106.4	84.7	79.6	70.6	83.4	74.5	56.6	82.1	68.1	41.3
			20.4%	25.2%	33.6%	21.6%	30%	46.8%	22.8%	36%	61.2%
	Soybeans	32.4	32.4	32.4	32.4	32.4	32.4	28.5	32.4	32.4	20.7
			0%	0%	0%	0%	0%	12%	0%	0%	36%

(Note: Numbers in percentage denote the % loss in crop yield with respect to their yield now. Now means the yield of crops in 2017)
L = Salinity rises at low rate, M = Salinity rises at medium rate, H = Salinity rises at high rate

Chapter 4. Modeling Economic Impact

4.1 IMPLAN

In the previous chapter, I calculated the potential decrease in crop yield in different slope and time scenarios. A significant reduction in yield of crops was found when the rate of salinity rise was medium or high. In this chapter, I estimate the economic impacts of crop yield loss on the economy of the region using an input-output modeling approach. Input-output modeling is mostly utilized to produce the estimates of economic impacts at the regional level (Drucker, 2015). According to Miller and Blair (2009), input-output models produces economic impact estimates by tracking dollar transactions between consumers, industries, and the public sector, reflecting the interdependencies between these economic agents involved. The input-output model tracks how goods and services flow through the economy and are commonly used to assess the impacts of inflow of private or government expenses into a region on jobs created, consumption and output (USDA/NRCS, 2014).

To assess the economic impacts, this study uses IMPLAN⁶, a ready-made, secondary data constructed input-output based model that contains detailed information about all the economic activities at the state and county level for the entire U.S. This model can be used to

⁶ © 2012 IMPLAN Group LLC, 16905 Northcross Drive, Suite 120
Huntersville, NC 28078. <http://www.implan.com>. IMPLAN is widely used in conducting economic impact analyses for different places. This study used the Version 3 model of IMPLAN which has the capacity of calculating multi-region analyses by accounting for county to county trade flows.

assess the economic impact of yield loss in crops (rice, corn and soybeans) on the local as well as state economy together with a detailed analysis of negative changes that occur in the economy when there is significant reduction in crop yield. The agricultural sector in Louisiana plays a very important role in the state's economy by creating employment and income for local residents through the operation of farming and other farming-related enterprises. Specifically, production of crops creates job and generates income in other businesses such as agricultural input suppliers. Further, retail and service sectors across the state are also impacted by the spending of incomes directly earned by farmers as well as the indirect incomes spent from input suppliers. This study focuses on estimating the economic contribution of crop production on the regional and state economy by using the value of total revenue generated through crop production as well as the economic impacts of lost revenue due to salinity induced crop yield losses on the larger regional economy.

In section 4.2 I will explain the methodology for conducting impact analysis through IMPLAN and describe about the methods and data used for impact analysis. Similarly, in section 4.3, I will estimate the total contribution of irrigated crop production on the 17 parish region in 2017 together with the total economic impact of salinity induced crop yield loss in the future for four different time and salinity scenarios. Furthermore, in section 4.4, I will conduct impact analyses to estimate the total regional economic impact of alternative solutions to the salinity problem in crops. At the end of section 4.4, I will discuss the limitations of using IMPLAN for impact analysis in this study.

4.2 Methodology

Although I look at the production of crops like rice, corn, soybean, cotton, wheat, and sorghum in 17⁷ parishes, a big part of the revenue generated from sale of crop products comes from other parishes of Louisiana. There is a spillover effect of crop production from the studied 17 parishes to all other parishes in Louisiana. Similarly, revenue generated from crop production influences other economic activities within the same parish and neighboring parishes in the region. The economic rationale behind this method is grounded on the premise that revenue generated from crops will flow to some other economic activity involving trade of goods and services which yields a positive contribution on the economy. This study estimates the indirect and induced impacts of a given level of crop production or change in the crop production system using the IMPLAN model and proprietary databases.

IMPLAN calculates the total economic impact as a sum of direct, indirect and induced impacts. Direct impacts occur as a result of economic activity within the crop production complex such as total employment created in the sector, total sales and purchases of primary and secondary crop products, and other crop by-products and total spending on farm inputs. Similarly, indirect impacts are those impacts which occur as a consequence of expenditures by other industries or businesses that support crop production. Additional demand of goods and

⁷ The 17 parishes include parishes under two regions (MRAA and Chicot). Parishes studied under Chicot are Acadia, Allen, Calcasieu, Cameron, Evangeline, Jefferson Davis, and Vermilion. Parishes in MRAA are Avoyelles, Catahoula, Concordia, East Carroll, Franklin, Madison, Morehouse, Richland, Tensas and West Carroll

services is created by these expenditures which induces the supporting businesses to produce more to meet the new market demand and thus result in indirect impacts. Furthermore, induced impacts reflect the expenditures created by demand for local goods and services by farm employees and indirect business employees. Direct and indirect employees spend their wages and salaries on items such as food, housing, entertainment, transportation, health services, etc. This demand generates additional demand for goods and services which again needs to be produced by firms by hiring employees and purchasing inputs. The sum of all these repeating economic activities creates total induced impacts.

Similarly, IMPLAN gives us a multiplier value for all economic indicators. The multiplier reflects the recycling of economic value (dollars) of a particular production sector in a specific geographic region, such as the parishes of Louisiana. . Recycling of dollars from one sector creates new jobs and income sources in other sectors. For example, the 2015 employment multiplier for crop (rice, corn and soybean) production in 17 parishes is estimated as 1.9. This means that every 100 jobs in the crop production sector supported an additional 90 jobs within the region.

IMPLAN is an economic model containing the detailed information and databases of a regional economy and it is widely utilized for analyzing economic impacts. A regional model

consisting of 17 parishes and a state model is built using 2015⁸ IMPLAN data sets for each model. For the analysis, I chose the default settings in IMPLAN. I built the model through multipliers and I used the IMPLAN National Trade Flows Model as the trade flow method. The model I build was closed with respect to the household institutions and government (local and state as well as federal). This means the total economic contributions would include induced related effects driven by household consumptions as well as local, state, and federal government spending linkages.

4.2.1 Data

For the contribution analysis, I need information about the direct impact created from production of crops. In this study, the direct impact is the total revenue generated from the sales of crop products. When there is loss of crop yield due to salinity, then the direct impact is the total loss in revenue caused by the decrease in total crop production. For this study, I used the data of total irrigated crop acres in the 17 parishes provided by the USDA/FSA (2017). Similarly, data of average yield and market price of crops in the year 2017 is obtained from the USDA/NASS database of Louisiana. These data are used to calculate total revenue generated which makes up the initial final demand that is applied to the IMPLAN model. Furthermore, this

⁸ This study used 2015 IMPLAN data sets to conduct impact analysis for 2017. I used 2015 data sets based on the idea of relative stability of the local economy in the parishes of Louisiana. According to Drucker (2015), impact analysis techniques assume that the local economy has some degree of economic stability over some period of time. The 2015 to 2017 period is a short-time window; as a result, it should be less problematic for conducting the impact analysis in this study using the 2015 data.

analysis makes use of IMPLAN's proprietary databases on parishes of Louisiana and the whole state relating to employee compensations, and their expenditures on goods and services.

4.2.2 Method

In this study, I used the following method to measure initial final demand. In particular, I use the following formula to estimate the direct contribution of crop production.

$$\text{Direct Contribution (Impact)} = \text{Total Revenue} = \text{Crop acres} * \text{Average yield} * \text{Average market price}$$

This same formula can be used if the cropping system is changed or irrigated crop acres are switched to other crops. Whenever a loss in crop yield due to salinity is observed, then the direct impact also decreases for such conditions. It is assumed that when yield is reduced from salinity or there is a change in cropping systems, the final demand that was previously met by the region (or state) is reduced by the lost production from reduced yield. This lost final demand is calculated through the aforementioned formula for total revenue.

4.3 Economic impact of irrigated crop production

Based on the water use data provided on water resources special report no. 17 (revised) of the year 2010 by the Department of Transportation and Development, a total of 17 parishes were studied, where rice, corn and soybean were grown in irrigated acres in significant amount and were found to be almost fully dependent on groundwater withdrawn from the two aquifers for irrigation. Parishes of the Chicot region under study are Acadia, Allen, Calcasieu, Cameron, Evangeline, Jefferson Davis, and Vermilion. While those in the MRAA are Avoyelles, Catahoula, Concordia, East Carroll, Franklin, Madison, Morehouse, Richland, Tensas and West Carroll. Almost all of the irrigated crop producing areas overlying the Chicot aquifer produce rice while

those areas overlying the MRAA mainly produced rice, corn, soybean and cotton. However, cotton is not included in this study.

Table 4. 1. Total Economic Contribution of Irrigated Crop Production on the Economy of 17 Parish

Impact Type	Employment	Labor Income	Total Value Added	Output
Direct Effect	3,522	\$ 183,945,320	\$ 229,490,026	\$ 752,935,377
Indirect Effect	2,048	\$ 83,119,013	\$ 133,845,698	\$ 245,374,503
Induced Effect	1,132	\$ 38,958,907	\$ 75,711,247	\$ 136,465,011
Total Effect	6,702	\$ 306,023,240	\$ 439,046,972	\$ 1,134,774,891
Multiplier	1.9	1.7	1.9	1.5

Employment = Full-time and part-time jobs directly and indirectly supported by farming

Labor income = Total employee compensation and non-corporate proprietor income including benefits

Total Value Added = Total output minus intermediate outputs

Output = The value of expenditure directly and indirectly supported by crop production

Table 4.1 presents the IMPLAN results representing the total economic contribution of crop (rice, corn and soybean) production on the 17 parish region. By using the revenue formula described in section 4.2.2, I calculated the total revenue generated in 2017 from the crops. The total revenue generated is the value of initial demand for crop commodities grown in this region. When applying the initial final demand to the IMPLAN model, Table 4 shows that the total economic contribution of crop production to the region was approximately 6,702 jobs, \$306 million in labor income, \$439 million in total value added and \$1.13 billion in total economic output. It shows an employment multiplier of 1.9, which indicates that for every 100 jobs directly supported by crop production, 90 additional jobs were created in other sectors within the region. For the total output, the multiplier is 1.5 which indicates that an additional

\$50 was generated in the region in other sectors for every 100 dollars of crop value initially demanded from the crop production sector.

Table 4. 2. Total Economic Contribution of Irrigated Crop Production on the Economy of Louisiana

Impact Type	Employment	Labor Income	Total Value Added	Output
Direct Effect	3,702	\$ 155,246,021	\$ 229,490,129	\$ 752,935,377
Indirect Effect	2,742	\$ 119,155,395	\$ 226,669,344	\$ 435,463,976
Induced Effect	1,559	\$ 63,867,427	\$ 115,772,309	\$ 202,275,018
Total Effect	8,003	\$ 338,268,843	\$ 571,931,782	\$ 1,390,674,370
Multiplier	2.2	2.2	2.5	1.8

Employment = Full-time and part-time jobs directly and indirectly supported by farming

Labor income = Total employee compensation and non-corporate proprietor income including benefits

Total Value Added = Total output minus intermediate outputs

Output = The value of expenditure directly and indirectly supported by crop production

Similarly, table 4.2 contains the result of impact analysis showing the total economic contribution of crop production on the state. The result shows that production of irrigated rice, corn and soybean in the aforementioned 17 parishes has created approximately 8,003 jobs, contributed about \$338.3 million in labor income and generated an approximate output of \$1.39 billion in the entire state. While analyzing the total economic contribution on all parishes in Louisiana, I find that total jobs created within the state was more than the total jobs created on those 17 parishes. This indicates that the crop production sector of the region generates additional 1,301 jobs outside the region but within the state. Similarly, it can be seen that the production of irrigated rice, corn and soybeans generates approximately \$1.39 billion worth of output for the entire state in which about \$1.13 billion is generated within the 17 parishes while the remaining comes from other parishes. Higher multipliers in table 4.2 compared to

table 4.1 for all four indicators of the economic contribution highlight the fact that much of the indirect demand for business inputs as well as household spending of farm labor and farm proprietors in the 17 parish region occur outside the region in other areas of the state.

4.3.1 Economic impacts of loss in crop yield due to salinity

In this section, IMPLAN is used to estimate the impact of salinity induced loss in yield of rice, corn and soybeans on the overall economy of the 17 parish region. Table 3.3 contains the predicted loss in crop yield for nine different future scenarios. The calculated lost revenue is the direct impact of crop yield loss, which is used by IMPLAN to analyze the total impact on the economy. While I perform the impact analysis for all nine scenarios of crop yield loss, in this study I only focus on four scenarios which have relatively higher impacts on the economy. The four scenarios are:

- a) salinity rise with medium slope in 20 years;
- b) salinity rise with high slope in 20 years;
- c) salinity rise with medium slope in 30 years, and
- d) salinity rise with high slope in 30 years.

In this study, I have projected what the salinity induced yield loss in crops would be in the 20th and 30th year from 2017 when salinity rises with medium and high slope producing yield loss results for four different scenarios mentioned above. After predicting the yield loss, I have evaluated the economic impact in those scenarios by considering if those yield losses in crops as predicted in future would have occurred in 2017. I have used this approach because it would be easy to estimate and interpret the net economic impacts to the region when I evaluate with respect to current economic condition of the 17 parish region. There is

uncertainty about how the economy would be like in next 20 or 30 years, so I perform all the impact evaluations treating the salinity impacted yields in the 20th or 30th year and any alternative crop systems on the regional economy of 2017 so the scenario results can be more comparable.

Table 4. 3. Economic Impact of Salinity Induced Crop Yield Loss for Irrigated Crops under different slope and time scenarios

Scenarios	Total Regional Economic Contribution/Loss		% loss from baseline scenario	
	Employment	Output (\$)	Employment	Output
Irrigated crop production (Baseline scenario)	6,702	1,134,774,891	-	-
Salinity induced crop yield loss (Medium slope in 20 years)	914	139,837,987	13.6	12.3
Salinity induced crop yield loss (High slope in 20 years)	1,952	311,655,843	29.1	27.5
Salinity induced crop yield loss (Medium slope in 30 years)	1,177	180,033,533	17.6	15.9
Salinity induced crop yield loss (High slope in 20 years)	3,066	508,351,533	45.7	44.8

Note: Baseline scenario represents irrigated crop production in 2017 and the numbers in that scenario denote the total contribution of crop production to the regional economy.

IMPLAN summary tables for all four scenarios highlighted above (table 4.3) are presented in more detail in appendix 2. Table 4.3 contains the results of comparative economic impacts of salinity induced yield loss in irrigated rice, corn and soybean on the region for the aforementioned four scenarios. When salinity rises with a medium rate, in 20 years, total loss on the regional economy due to salinity induced yield loss would be about \$140 million in total output and 914 jobs. Similarly, for the scenario after 20 years, if salinity increases at a high rate, the regional economy will suffer a total loss of \$311 million in output and more than 1,900 jobs.

Furthermore, the results show that in 30 years, a total of 3,066 jobs will be lost along with a huge sum of output which will be more than \$500 million due to the loss in crop yield if salinity increases at a high rate. Such high reduction in output and employment could be devastating to the regional economy. Results from Table 4.3 highlight that salinity can be a sizeable threat to the agricultural economy and possible solutions have to be considered if these economic losses are to be avoided in the future.

4.4 Economic impacts of alternative solutions to salinity problem.

This section of the paper investigates the possible alternative cropping practices which can be adopted in the region in order for crop production to be sustainable under high salinity conditions of future. After identifying the alternate cropping systems, the study investigates the economic impacts of these alternate methods and determine their effectiveness in preventing the negative impacts of salinity. This study explores three alternative solutions for addressing the salinity problem which include:

- a) growing novel crop varieties which are tolerant to salt stress;
- b) switching the cropping system from irrigated to non-irrigated, and
- c) switching to other crops which are more salt tolerant.

4.4.1 Economic impacts of growing novel crop varieties which are tolerant to salt stress

Replacing salt sensitive crops by varieties more tolerant to saline conditions of the same crops has been proposed by several studies as the most promising solution to prevent salinity-induced yield loss in crops. Many novel varieties of rice, corn and soybean have been successfully grown in several countries of the world which are tolerant to salt stresses and have produced in a high-yielding manner. In this section, I take a close look at the economic impacts

of growing salt tolerant crop varieties of the same crops rather than the existing salt sensitive varieties, which will potentially face an enormous loss in yield in the future, should the soil salinity increase in the future. Like Table 3.3, I build a yield loss scenario for both salt sensitive varieties and salt tolerant varieties of the same crops in the future, should the salt level in the MRAA and Chicot aquifers keep on increasing at the predicted rate. Unlike Table 3.3, I only look at one scenario to estimate the predicted yield loss in these crops, which is 30 year scenario, should the salinity increase rate follow the high trend. Then the predicted outcome from the yield loss is compared for salt sensitive varieties and salt tolerant varieties of same crop.

Many varieties of rice, corn and soybeans which can withstand salt stress and produce improved yields have been developed and introduced in many countries around the world. As discussed in section 2.1, a few crop varieties have been found to be promising in salt affected areas. Although these salt tolerant varieties of rice, corn, and soybeans have not been tested in the climatic and edaphic conditions of Louisiana, this study attempts to provide a picture of possible outcomes in the future, should the existing salt sensitive crop varieties be replaced by salt tolerant varieties. Furthermore, IMPLAN is used to analyze the economic impact of using salt tolerant varieties of rice, corn, and soybeans instead of the existing varieties, on the total economy of 17 parish region.

Table 4.5 shows the comparison between the potential salinity induced yield loss in salt sensitive and salt tolerant crop varieties of rice, corn, and soybeans. In the Table, the present yield and the predicted yield after 30 years for each crop variety is shown, together with the percentage loss in yield. As shown in Maas and Hoffman (1977), I have categorized the crops having a threshold level of salinity of 5 or more than 5 mmhos/cm as tolerant or moderately

tolerant to salt stress except for soybeans (threshold salinity 5 mmhos/cm), which according to their findings, is moderately tolerant. However, several recent studies have categorized soybeans as a salt sensitive crop. Therefore, considering the respective salt tolerance levels, I have assumed the tolerant varieties of rice and corn to have at least a threshold salinity value of 5 mmhos/cm and for tolerance for soybeans, the value would be at least 6 mmhos/cm.

Table 4. 4. Comparing between yield loss in salt sensitive and salt tolerant crop varieties due to salinity (high slope in 30 years)

Aquifer	Salinity in mmhoscm ⁻¹		Crops	T.S.L	Slope	Yield in cwt/acre	
	Now	In 30 years				Now	In 30 years
Chicot	2.8	6.3	Existing rice cultivars (salt sensitive)	3.0	12	67.1	40.5 (39.6%)
			Novel rice cultivars (salt tolerant)	5.0	12	67.1	56.6 (15.6%)
MRAA	3.3	6.8	Existing rice cultivars (salt sensitive)	3.0	12	67.1	36.5 (45.6%)
			Novel rice cultivars (salt tolerant)	5.0	12	67.1	52.6 (21.6%)
			Existing corn cultivars (salt sensitive)	1.7	12	106.4	41.3 (61.2%)
			Novel corn cultivars (salt tolerant)	5.0	12	106.4	83.4 (21.6%)
			Existing soybean cultivars (salt sensitive)	5.0	20	32.4	20.7 (36%)
			Novel soybean cultivars (salt tolerant)	6.0	20	32.4	27.2 (16%)

T.S.L = Threshold salinity level in mmhoscm⁻¹

Slope = Percentage loss in yield per unit rise in salinity beyond T.S.L

Values inside parenthesis in the last column are the loss in percentage of respective crop yield

Source: Analysis using T.S.L and slope data of crops from Maas and Grattan (1999)

I estimate the yield loss by utilizing the mathematical equation provided by Maas and Hoffman (1977), using the threshold salinity and slope value of respective crops. It is also

assumed that the salt tolerant cultivars would have the same yield as salt sensitive cultivars, but under non-saline field conditions. Results of Table 4.4 show that despite using salt tolerant crop varieties, there will still be some amount of loss in crop yield. However, the decrease in yield is much less compared to the scenario where no change is made in the existing cropping system.

Table 4. 5. Total economic impact of salinity induced yield loss of salt-tolerant crop varieties and comparison with no change scenario

Scenario after 30 years	Baseline scenario		Total loss after 30 years w.r.t. baseline scenario	
	Emp	Output(\$)	Emp	Output(\$)
No change in cropping system	6,702	1,134,774,891	3,066	508,351,533
Adoption of salt-tolerant varieties			1,202	201,346,954

(Note: The baseline scenario indicates the total economic contribution of irrigated crop production on the 17 parish region in 2017. Numbers in the table other than for baseline scenario show the lost values due to salinity induced crop yield loss for respective scenarios)
Emp = Employment, w.r.t = with respect to

Utilizing the information of crop yield loss projected in table 4.4, the total loss in crop value for salt tolerant crops is calculated by using the formula specified in section 4.2.2. In the formula, I use the yield value which is reduced due to salinity and determine the total loss in revenue generated from crops which signifies the loss in initial final demand of crops. The estimation is performed for the 30 years scenario when salinity increases at the high rate. Predicted loss in yield under adoption of salt tolerant crops leads to a total crop value loss of \$133,704,760 which is substantially lower compared to \$337,846,199, which is the direct loss when existing crop varieties are grown. Results of the analysis from IMPLAN are shown in table 2E (see appendix 2). Meanwhile, table 4.5 shows the total regional impact of salinity induced yield loss in salt tolerant varieties of rice, corn and soybeans with respect to the baseline scenario. The baseline scenario indicates the total economic contribution of the irrigated crop

(rice, corn and soybeans) production on the 17 parish region in 2017 which is shown in Table 4.5. Similarly, table 4.5 also presents the direct comparison with the total impact of yield loss when no change is made in the existing cropping system. The regional economic impact is shown in terms of loss in total employment and total output. Results from table 4.5 show that salinity induced yield loss in salt-tolerant crop varieties will lead to a loss of 1,202 jobs and more than \$200 million in terms of total output in the 17 parish region. It can be seen from table 4.5 that, with respect to the baseline scenario, total jobs and output lost under the existing cropping system is much higher than the alternate scenario where salt tolerant crops are adopted. This signifies that growing salt tolerant varieties of rice, corn and soybean can be an optimum alternative to prevent sizable economic losses on the 17 parish region.

4.4.2 Economic impacts of switching from irrigated to non-irrigated cropping system to prevent irrigation induced salinity.

The development of salinity in agricultural lands overlying the two aquifers (MRAA and Chicot) is due to irrigation using saline groundwater. With an increase in irrigated farm lands, more water will be withdrawn to meet the water needs of crops, which will actually increase the risk of a rise in salt concentration in these aquifers. To prevent this calamity, the withdrawal of water from the aquifers can be minimized by changing the cropping system from an irrigated to non-irrigated one. By switching to a non-irrigated cropping system, the development of irrigation induced soil salinity may be prevented. A switch to non-irrigated farming from irrigated farming, depending on the suitability of the land, will likely reduce the amount of groundwater extracted from the aquifers which can prevent the formation of cones of depression in the aquifers. Formation of a cone of depression displays a main phenomenon that causes salt intrusion from underlying tertiary aquifers into the MRAA and Chicot aquifers.

Hence, salt intrusion from tertiary aquifers into primary aquifers may be consequentially prevented by extracting a minimal amount of water from the aquifers by adopting non-irrigated farming practices. Therefore, switching irrigated crop acres to non-irrigated acres can potentially solve the salinity problem in two ways: preventing secondary salinization of soil by minimizing the use of saline groundwater which will ward off the salinity induced yield loss problem in crops, and drastically reducing water withdrawal from the aquifers, which will decrease the chance of formation of cones of depression in these aquifers, thus preventing salt intrusion.

Table 4.6 shows a possible framework for switching the cropping system from irrigated to non-irrigated in 17 parishes. Since rice is the only major irrigated crop grown in the Chicot region, irrigated rice acres are switched to any other major non-irrigated crop grown in that region. According to FSA (2017) data regarding irrigated crop acres in Louisiana, sugarcane is the major crop grown under a non-irrigated system in Vermillion parish. Similarly, in six other parishes of Chicot region, non-irrigated soybeans are significantly grown. Rice, soybeans and corn are the major irrigated crops grown in the MRAA region. Since non-irrigated rice farming is not practiced in the region, irrigated rice acres in each parish are switched to non-irrigated acres of other crops, which are significantly grown in the respective parish. On a similar basis, irrigated corn and soybeans are switched to non-irrigated cropping systems with the same or different crop depending upon the dominant, non-irrigated cropping system prevalent in the parish. According to FSA (2017) data in Richland parish, while non-irrigated soybean farming is practiced in a large area, non-irrigated corn production is almost non-existent. Therefore, irrigated acres of these three crops are switched to non-irrigated acres of soybean in Richland

parish. Yet, in other parishes of the MRAA region, a significant production of both non-irrigated corn and soybeans is found. Hence, as seen in Table 4.6, in parishes other than Richland Parish in the MRAA region, acres producing irrigated rice and soybean are switched to a non-irrigated soybean system, while irrigated corn is switched to a non-irrigated system.

Table 4. 6. Switching the cropping system from irrigated to non-irrigated for same crop or different crop

Aquifer	Parishes	Existing Crops (Irrigated)		Other Crops (Non-irrigated)
Chicot	Acadia, Allen, Calcasieu, Cameron, Evangeline, Jefferson Davis	Rice	to	Soybeans
	Vermilion	Rice	to	Sugarcane
MRAA	Avoyelles, Catahoula, Concordia, Franklin, Madison, Morehouse, Tensas, East Carroll, West Carroll	Rice, Soybeans	to	Soybeans
		Corn	to	Corn
	Richland	Rice, Corn, Soybeans	to	Soybeans

For the crop switch scenario presented in this section, it is considered that this is an extreme scenario where existing crop practices would fail and a switch to an alternative cropping practice must be performed to sustain the agricultural productivity in the region. Following a scenario where the cropping system is switched from irrigated to non-irrigated, the total crop value generated from the non-irrigated crop production is estimated. An estimated total of \$579,859,375 as the total crop value is generated when non-irrigated crops (soybean, corn and sugarcane) are produced in those acres where the production of irrigated rice, corn and soybeans was prevalent earlier. This value is the direct impact of a new cropping system on the economy and also the initial final demand. By using this direct impact value, IMPLAN

generates a total economic impact of non-irrigated crop production on the economy of the 17 parish region. Table 2F (see appendix 2) presents the detailed impact summary for non-irrigated crop production.

Table 4. 7. Total economic impact of switching to a non-irrigated cropping system and comparison with the no change scenario when salinity increases at a high rate

Cropping system	Economic impact in 2017		Economic impact in 30 years		Loss in 30 years w.r.t baseline scenario*	
	Emp	Output(\$)	Emp	Output(\$)	Emp	Output(\$)
Irrigated	6,702*	1,134,774,891*	3,636	626,423,358	3,066	508,351,533
Non-irrigated	5,086	907,874,226	5,086	907,874,226	1,616	226,900,665

(Note: * denotes the baseline scenario i.e. the total economic contribution of irrigated crop production on the 17 parish region in 2017)

Emp = Employment, w.r.t = with respect to

In the current scenario, when the soil salinity hasn't developed to harmful levels, if all irrigated crops were switched to a non-irrigated system, the total contribution of non-irrigated crop production in the economy would be significantly less than the total economic contribution of irrigated crop production, as can be seen in the results of table 4.7. This is because less revenue will be generated from non-irrigated crops due to the lower yield of crops under the non-irrigated system. According to the budget data from the LSU Ag Center (2017), average yield of non-irrigated soybean is less than the average yield of irrigated soybeans by 10 bu/acre. Similarly, average yield of irrigated corn exceeds the average yield of non-irrigated corn by about 30 bu/acre. For non-irrigated conditions, highly minimized use of saline groundwater for irrigation will lead to a scenario where even in the coming decades, soil salinity will not reach harmful level for the crops. Other things remaining constant, there will be no salinity induced yield loss in crops, and the economic output from crop production will remain approximately the same 30 years from now for the non-irrigated system, as can be seen in the

results of Table 4.7. Looking at the numbers in Table 4.7, one can infer that switching from an irrigated to non-irrigated cropping system will not be a prudent decision to undertake under the current scenario where the soil salinity hasn't reached detrimental level for crops like rice, corn and soybeans. However, unlike the non-irrigated system, the prevalence of the irrigated cropping system will lead to paramount economic losses in the future (see section 4.3). In this section, I will only consider the scenario after 30 years if salinity keeps on increasing at a high rate. In table 4.7, I present the direct comparison between the economic impacts of crop production when no change in cropping system is made and when the cropping system is switched to non-irrigated system in 30 years under high rate salinity rise condition. Total loss in the respective scenarios is calculated by comparing the total impacts with impact results of baseline scenario. The baseline scenario impact reflects the total economic impact of irrigated crop (rice, corn and soybean) production on the 17 parish region. According to results of Table 4.7, switching to a non-irrigated system will decrease the total economic loss by about half compared to the no change scenario in 30 years under high slope of salinity rise. In 30 years from 2017, reduced loss in jobs and output is observed under the non-irrigated system because the non-irrigated cropping system will have the advantage of being unaffected from the irrigation induced salinity problem. Due to this reason, when the soil salinity reaches harmful level after 30 years, non-irrigated farming can generate more returns than irrigated farming. By looking at the economic benefits in terms of total jobs created and total output generated, as presented in Table 4.7, it can be seen that switching from irrigated farming practices to non-irrigated practices may be a good alternative to prevent negative impacts of salinity on agricultural production as well as on the whole regional economy.

However, non-irrigated farming may not always be the optimal alternative (in terms of regional economic benefits). Even should there be an extremely low possibility of salt accumulation from saline irrigation water, other factors may contribute to the development of soil salinity. During periods of drought, inadequate leaching of salts present in the soil can lead to salt accumulation in soil layers. Similarly, presence of a brackish groundwater table can cause infusion of salt into the soil as the water table rises. According to Stuart et al. (1994), the water table in the MRAA and Chicot region is very shallow in many areas. Presence of a shallow underground saline water table can induce soil salinity in agricultural lands. Therefore, better strategies have to be explored to prevent yield loss of crops due to soil salinity. Growing salt tolerant crops like cotton, wheat, barley and sorghum can be a valuable strategy to prevent salinity induced yield loss in crops. This study explores the economic impacts of this alternative in the upcoming section, and investigate whether growing salt tolerant crops would be a better solution to the salinity problem.

4.4.3 Economic impacts of switching to other crops which are more salt tolerant.

Crops like cotton, wheat, barley and sorghum are more tolerant to salt stress than rice, corn and soybean. Among salt tolerant crops, cotton is cultivated in Louisiana, and these areas overlying the MRAA and Chicot aquifer are responsible for more than two thirds of total production of cotton in Louisiana. Among other salt tolerant crops, barley is produced on very little acreage in the state and is not considered a major crop. According to USDA/FSA (2017), large scale sorghum production is limited to a few parishes like Avoyelles and Tensas while very few acres in Catahoula and Morehouse are cultivated for producing sorghum. Similarly, wheat is also produced on a small scale in some parishes of the region. Since cotton, sorghum and

wheat are tolerant to salt stress and grown in the MRAA region, switching the cropping system from salt sensitive crops like rice, corn, and soybeans to these salt tolerant crops can be a good strategy to prevent salinity induced crop yield loss in the future. Farmers can grow salt tolerant crops in the region instead of growing the prevalent salt sensitive crops, depending on the feasibility of switching from one cropping system to another. The feasibility of switching from one crop to another might depend on several factors such as soil conditions, irrigation requirements, and climatic conditions, together with the demand for the commodities in the region.

Switching from one crop to any other crop may be more practical if the other crop is also significantly grown in the region, since it reflects the similarities between the two crops in terms of their requirements for climatic, edaphic and other factors present in that particular region. For this study, I have created a possible scenario for switching from rice, corn and soybean cultivation to wheat, sorghum and cotton in the MRAA and Chicot regions based on the significant crop grown in the parish where changes in cropping system is to be made. However, unlike in the MRAA, only rice is the major irrigated crop grown in Chicot region and production of salt tolerant crops like cotton, wheat and sorghum in irrigated acres is very low in the region. Rice farming is switched to wheat farming in the irrigated acres of Chicot region to prevent the potential yield loss in crops due to increased salinity in future. The potential switching of crops as presented in this section is considered to be an extreme scenario which would be the aftermath of salinity induced yield loss of existing crops in the 30th year, likely leading to crop failure under some extreme conditions. Following the establishment of a possible crop switch scenario in Table 4.8, I conduct an impact analysis for a future scenario

where the cropping system is switched from existing salt sensitive crops (rice, corn and soybeans) to salt tolerant crops (wheat, sorghum and cotton). After the impact analysis is performed, the results will be compared with the economic impact results of the status quo scenario when no change in cropping system is made in 30 years.

Table 4. 8. Switching of cropping system from salt sensitive crops (rice, corn and soybean) to salt tolerant crops (wheat, sorghum and cotton) for 17 parishes

Aquifer	Parishes	Existing Crops		Salt tolerant Crops
Chicot	Acadia, Allen, Calcasieu, Cameron Jefferson Davis, Evangeline, Vermillion	Rice	To	Wheat
MRAA	Avoyelles, Catahoula, Morehouse, Tensas	Rice, Corn	To	Sorghum
		Soybeans	To	Cotton
	Concordia, Franklin, Richland, East Carroll, West Carroll	Rice, Corn	To	Wheat
		Soybeans	To	Cotton
	Madison	Rice, Corn, Soybeans	To	Cotton

Table 4.8 contains the information about the crop switch from existing salt sensitive crops to salt tolerant crops for every parish in the region. In all parishes on the Chicot region, rice production is switched to wheat production. Similarly, in the MRAA region, all three existing crops (rice, corn and soybeans) are switched to a cropping system adopting three salt tolerant crops (wheat, sorghum and cotton) depending on the crop switch feasibility of each parish. Table 4.9 shows the potential yield loss due to salinity for the three salt tolerant crops. For each salt tolerant crop, Table 4.9 presents a firsthand comparison between their current yield and their potential yield after 30 years when salinity has increased in a high rate. I have used the threshold salinity value and slope value of the three crops provided by Maas and Grattan (1999) for calculating the yield loss of crops. From the results of table 4.9, it can be

seen that in 30 years, if salinity keeps on increasing at a high rate, yield loss will be seen in wheat while other crops (cotton and sorghum) will be unaffected by increased salinity. The reason behind this is the high threshold salinity value of sorghum and cotton which keeps them thriving in such high saline conditions. In the specified future scenario, yield loss in wheat will be about 2.1% in the Chicot region and 5.7% in the MRAA region. By utilizing the yield result obtained from Table 4.9 on the total acres switched to a new cropping system, I estimate the total crop value of the three salt tolerant crops in the 17 parish region utilizing the total revenue formula (see section 4.2.2) and use the obtained value of total revenue as the direct output in IMPLAN to run the impact analysis for this scenario.

Table 4. 9. Potential crop yield loss due to salinity for salt tolerant crops when salinity increases at a high rate.

Aquifers	Salinity in mmhoscm ⁻¹		Crops	T.S.L	Slope	Yield in cwt/acre	
	Now	In 30 years				Now	In 30 years
Chicot	2.8	6.3	Wheat	6.0	7.1	27.6	27.0 (2.1% loss)
MRAA	3.3	6.8	Wheat	6.0	7.1	27.6	26.0 (5.7% loss)
			Sorghum	6.8	16	51.0	51.0 (0% loss)
			Cotton	7.7	5.2	9.0	9.0 (0% loss)

T.S.L = Threshold salinity level in mmhoscm⁻¹

Slope = Percentage loss in yield per unit rise in salinity beyond T.S.L

Source: Analysis using T.S.L and slope data from Maas and Grattan (1999)

By using IMPLAN, I create two scenarios to assess the feasibility and economic viability of switching the cropping system. In the first scenario, I looked at the economic impact for the current scenario when all the irrigated acres of the three existing salt sensitive crops of the region are switched to production of the three salt tolerant crops just like it is specified in table 4.8. The economic impact summary of the first scenario is present in table 2G (see appendix 2).

Similarly, in the second scenario I looked at the economic impact of the crop switch after 30 years when salinity has already increased to a detrimental level. The economic impact summary of the second scenario is present in Table 2H (see appendix 2). In Table 4.10, I have presented the comparative results of the economic impacts for different cropping systems in different time scenarios. For this study, I will only consider the future scenario after 30 years if salinity keeps on increasing at a high rate.

Results of Table 4.10 show that total economic contribution of production of salt-tolerant crops (wheat, cotton and sorghum) on the 17 parish region would be low compared to the contribution of existing crops. However, the contribution of salt-tolerant crop production on the economy would be much higher than that of existing crops after 30 years. The rationale behind this is the extremely low degree of yield loss observed in salt-tolerant crops even under increased salinity conditions of future. In table 4.10, I have also presented the total loss in economy under each cropping system which is estimated with respect to the baseline scenario. The baseline scenario reflects the total economic contribution of the irrigated crop (rice, corn and soybeans) production on the 17 parish region in 2017. It can be seen in table 4.10 that only 713 jobs and about \$250 million in terms of output will be the total loss to the regional economy after 30 years if the existing cropping system is switched to salt-tolerant crops. Total economic losses for salt-tolerant crop production is extremely low compared to the predicted losses under no change in existing cropping system, as can be seen in the results of Table 4.10. The number in table show that growing salt tolerant crops instead of the sensitive ones can potentially minimize the economic loss by more than 2,300 jobs and \$250 million in output, which can be a great benefit to the economy of the 17 parish region. One can conclude from

these results that growing salt tolerant crops instead of the existing salt sensitive crops may be a good alternative to prevent salinity problems in the future.

Table 4. 10. Total economic impact of salinity induced yield loss of salt tolerant crops and comparison with no change scenario

Cropping system	Economic impact in 2017		Economic impact in 30 years		Loss in 30 years w.r.t baseline scenario*	
	Emp	Output(\$)	Emp	Output(\$)	Emp	Output(\$)
Existing crops (no change)	6,702*	1,134,774,891*	3,636	626,423,358	3,066	508,351,533
Salt tolerant crops	6,021	888,882,436	5,989	884,041,921	713	250,732,970

(Note: * denotes the baseline scenario i.e. the total economic contribution of irrigated crop production on the 17 parish region in 2017).

Emp = Employment, w.r.t = with respect to

4.4.4 Comparing the economic impact of alternative solutions

In this section I compare the potential economic losses on the economy of 17 parish region for different cropping scenarios. The total impact created by the existing cropping system and alternative cropping systems after 30 years when salinity increases with a high rate is compared to the baseline scenario and total losses with respect to the baseline scenario are estimated.

The baseline scenario indicates the total economic contribution of the irrigated crop (rice, corn and soybeans) production on the economy of 17 parish region in 2017. Comparing the economic impacts after 30 years for existing and alternative crop scenarios with the baseline scenario and estimating the relative loss can give us a good idea about the relative advantages and disadvantages of each alternative cropping systems. In previous sections, I have estimated the total loss that will be observed in the economy with respect to the baseline scenario when alternative cropping practices are adopted to minimize salinity induced crop yield loss. In table 4.11, I have presented the direct comparisons between the economic scenarios created under

the adoption of different alternative cropping practices after 30 years for high rate of salinity rise.

Table 4. 11. Economic impact summary for the 17 parish regional economy for salinity induced loss in crop yield under adoption of different alternative solutions (high rate of salinity rise in 30 years)

Scenarios	Total regional economic impact		Loss in % of baseline scenario	
	Employment	Output (\$)	Employment	Output
Irrigated crop production (Baseline scenario)	6,702	1,134,774,891	-	-
Loss w.r.t baseline scenario (no change in cropping system)	3,066	508,351,533	45.7	44.8
Loss w.r.t baseline scenario (adoption of salt-tolerant varieties)	1,202	201,346,954	18.0	17.7
Loss w.r.t baseline scenario (switching to non-irrigated system)	1,616	226,900,665	24.1	20.0
Loss w.r.t baseline scenario (switching to salt-tolerant crops)	713	250, 732, 970	10.6	22.1

(Note: Baseline scenario represents the total economic contribution of irrigated crop production on the regional economy in 2017. Numbers in other scenarios denote the total loss in the economy with respect to the baseline scenario)

w.r.t = with respect to

The economic impact of all cropping scenarios considered in this study is presented in table 4.11 in the form of total employment and total output generated within the economy. Table 4.11 also shows the economic loss in each scenario in the form of loss percentage from the baseline scenario. From the results of table 4.11, it can be seen that total loss in employment will potentially be the least when one switches from the existing cropping system to other salt tolerant crops: cotton, sorghum and wheat. Total reduction in output generated is least when salt-tolerant varieties of rice, corn and soybean are grown. Hence, IMPLAN helps to evaluate the economic scenarios created by different cropping practices. Employment and total

output generated within the region can help one understand the net regional economic benefits of selecting alternative cropping practices in the future to prevent salinity induced yield loss.

Conducting impact analysis for a particular sector with respect to the regional or state economy using IMPLAN is a convenient technique to assess the economic contribution of that sector or the economic impact created due to changes in the sector. Unfortunately, the use of IMPLAN, like other input-output modeling system also comes with some limitations. In this section, I will discuss some limitations in the methodology I have used while conducting impact analysis. The first is the temporal limitation while estimating the economic impact of salinity induced crop yield loss for future scenarios. In this study, I have discussed some alternative solutions which involves switching of existing crops to non-irrigated system or other salt-tolerant crops to prevent loss from potential salinity problem after 30 years. Unfortunately, this study doesn't provide the information about the timing of when producers switch from existing cropping system to an alternative system. This study only discusses the specific time scenarios i.e. on the 20th and 30th year from 2017, assuming that crop switch is already performed before those specific time periods.

Similarly, the second limitation is the use of the revenue approach to quantify total final demand. Use of the revenue approach may underestimate or overestimate the true economic change that occurs in a region with respect to the change in revenue generated from a particular sector. This approach is incapable of linking backwards to directly account for the demand of goods and services created in another sector from which agricultural inputs are purchased. In this study, I haven't considered the change in inputs when cropping systems are

changed because the revenue approach assumes fixed use of inputs for crop production. Using total crop input expenditure as the initial final demand makes the impact analysis more realistic because it has a direct backward linkage to secondary sectors from which inputs are purchased which creates demand in those secondary sectors for additional goods and services, which creates a different mix and magnitude of indirect and induced effects. However, the change in revenue generated through crop production treats all the backward linkages to the demand for agricultural inputs the same when the production system uses the same crop but misses the differences in the input mix when that crop is applied in alternative systems (irrigated vs non-irrigated). This limitations suggest that while holistic accuracy (overall summed economic impacts) may have small errors in the estimate, one should be careful in looking at more detailed specific industry and household impacts from these results as the partitive accuracy may be more problematic.

Chapter 5. Summary, Conclusion and Limitations

This research addressed the increasing salinity problem from an economic perspective. The study area of this research consisted of the agricultural regions overlying two major aquifers: the MRAA and Chicot of Louisiana, with a focus on the impact of salinity for three major crops of this region: rice, corn and soybean. Studies by Nyman (1984), Lovelace (1999), Borrok and Broussard (2016), and Ramazan (2018)⁹ found that the salt content in the two aquifers show an increasing trend. The irrigation of crops using groundwater from these aquifers can result in secondary salinization of soil, inducing yield loss in crops. For rice, corn and soybean, areas overlying these two aquifers are jointly responsible for generating more than 75% of gross crop revenue of the entire state from the three crops. Therefore, a salinity induced crop yield loss in the study area may have serious impacts on the economy of the region, as well as the state. At present, the average soil salinity in the study region is found to be within a safe level for crops. Despite this fact, as groundwater salinity shows an increasing trend, the salt content of soil on farmlands will eventually surpass safe levels in the decades to come, and as a result, the crop yield will begin to decrease. Considering this problem, this study aims to assess the current trend of salinity increase, project the salinity level into the future, and prepare effective crop

⁹ Ramazan is a graduate student in the civil engineering department at LSU. The research group of my major advisor have been closely working with him and his major advisor on topics related to salinity in MRAA. Ramazan has been working on some models to find out the distribution of salts in MRAA.

management strategies to prevent yield loss from irrigation induced salinity for the decades to come.

A lack of uniformity in data for the increasing trend of salinity, as obtained from USGS chloride monitoring wells, guides this research to assume three different scenarios to project the possible rate of salinity rise in the two aquifers. With an estimate of the potential salinity after 10, 20, and 30 years, use of these three assumed salinity rise scenarios created a total of nine different future salinity conditions, ranging from a condition with a safe salinity level to a worst case condition of soil salinity. Using the obtained salinity values, I determined the yield loss in crops by utilizing the threshold salinity model given by Maas and Hoffman (1977). After an estimate of the yield loss in crops, this study assessed the total loss in revenue in terms of market price for crop produce. Using this lost revenue value, this study conducted an impact analysis for the salinity induced yield loss in crops. IMPLAN was used to model the impact analysis for the region and state. IMPLAN estimated the direct, indirect, and induced impacts of the production of the three crops (rice, corn, and soybeans) on the economy of the 17 parish region, as well as the entire state. With the help of IMPLAN, I projected how the salinity induced crop yield loss in the future would impact the overall economy of the region. Furthermore, this study identified three different alternate cropping systems which can be adopted in the region, so that the crop production will be sustainable under high salinity conditions of future, and used IMPLAN to conduct an impact analysis for each of these alternate practices. Through IMPLAN, this study investigates the economic impacts of each of these alternate cropping practices and determine their effectiveness after 30 years. For all of

these alternate practices, impact analysis was performed only for the regional economy by considering only one scenario: after 30 years with high rate of salinity rise.

The results of the impact analysis showed that production of irrigated rice, corn and soybean in the study region generates a total output of \$1.13 billion within the study region, while the total impact on the state in terms of total output generated was approximately \$1.4 billion. The crop production sector of the study region created more than 8,000 jobs within the state in 2017. This signifies that production of irrigated rice, corn, and soybeans on these 17 parishes have a measurable contribution to the economy of Louisiana. Similarly, I found that salinity induced loss in crop yield can be devastating to the regional economy as it can potentially induce a total loss of more than \$500 million in terms of total output generated over the region together with a loss of more than 3,000 jobs within the region. Furthermore, I conducted the impact analysis for three different alternative solutions to prevent salinity induced yield loss problem in crops. For the crop scenario after 30 years, the economic viability of these alternative cropping practices was closely investigated by looking at the total output and total jobs created, compared to that generated under existing cropping practice, should the salinity rise with a high rate. A comparison of the results found all of the alternative cropping practices to be better than the prevalent cropping system in terms of minimizing economic loss induced by salinity.

However, adoption of these alternative cropping practices may depend on several factors and these practices may not be feasible in all of the parishes under study. Their application in a particular region may depend on the climatic and edaphic conditions of that region or may be affected by the irrigation condition of the region. For example, climatic

conditions in the Chicot region may only be suitable for rice farming and growing other crops in that area will only lead to a failure. So, even if salinity keeps on increasing to a level where rice crop suffers significant loss in yield, replacing by other crops might not be able to compensate the loss in rice production. Although a scenario of growing spring wheat can be considered, there may not be wide acceptability to this suggested alternative. All of the possible practices to prevent salinity induced yield loss in crops described above haven't been successfully adopted in crop producing regions in Louisiana. Fortunately, since this study focuses on future condition rather than present condition, there is still time to explore more about the effectiveness of these alternative practices. A survey of farmers on what they consider as feasible alternatives to the current cropping system will help to identify economic impact more accurately.

There are two major limitations to the approaches I have used in this study. This study explores possible solutions to the salinity problem in crops only through the means of change in cropping system. One of the major limitation is that this study hasn't considered the methods or techniques other than the change in cropping system, to prevent the salinity problem in crops. Several land and water management techniques can be effective in controlling irrigation induced salinity. Efficient application of irrigation water can be a good strategy to reduce the buildup of salts in soil and this strategy is adopted in several salt affected regions around the world. The essence of this method is to supply only the amount of water to crops which they can actually use. Selecting efficient irrigation technologies along with appropriate scheduling of irrigation can prevent over-application of irrigation water. Minimizing the use of water for irrigation can ward off the accumulation of salts in the soil when irrigation water is saline.

Similarly, salt present in the crop root zone can be washed off to the lower layers of soil through appropriate leaching techniques, thereby preventing the long term accumulation of salts in the soil, which can slow down the process of salinization of the soil. Therefore, future approaches to this study should also focus on efficient irrigation techniques as an effective tool to prevent irrigation induced salinity in croplands. Other alternatives such as participation in wetland reserve and other conservation practices as well as switching to animal enterprises such as cattle, horses, or catfish are also possible but were not considered in this study.

Similarly, the other limitation is the use of the revenue approach to estimate the regional economic impacts of the crop production sector as opposed to using the cost approach. As I have already discussed above (see section 4.4.4), the cost approach likely produces more accurate estimates of demand created interdependently among different economic sectors. Hence, the direction in future for this research should be to consider a cost based analysis of the economic impacts of a particular crop production system.

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Appendices

Appendix 1. Trend of chloride concentration obtained from USGS chloride monitoring wells in different parishes.

Table A1. Wells in Madison parish

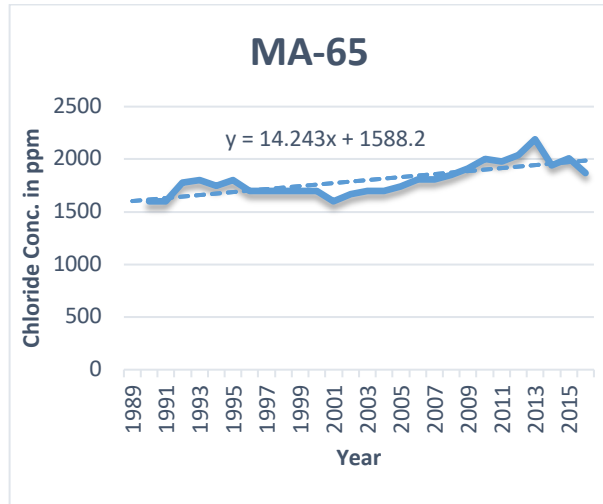
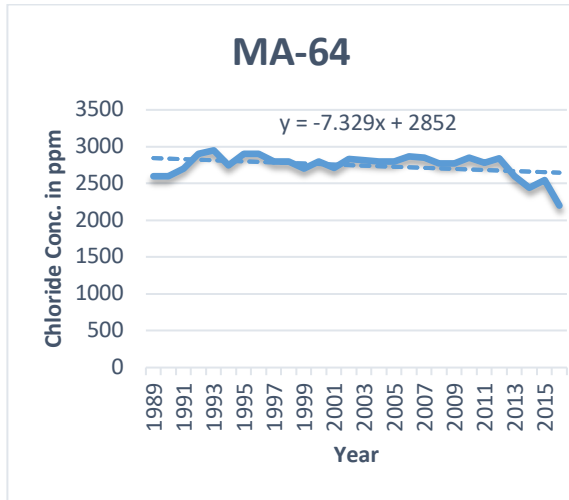


Table A2. Wells in Franklin parish

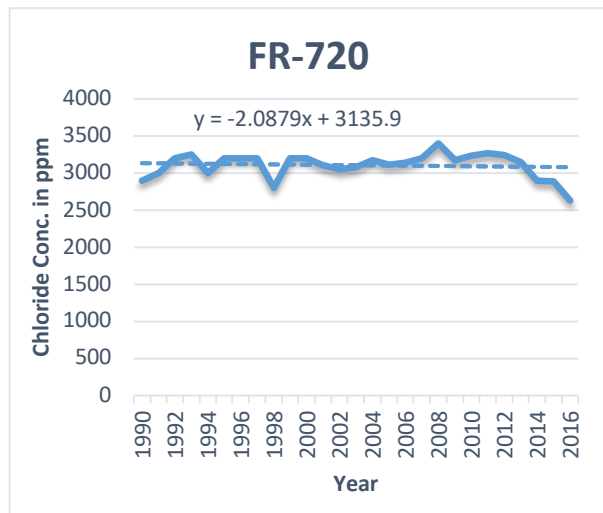
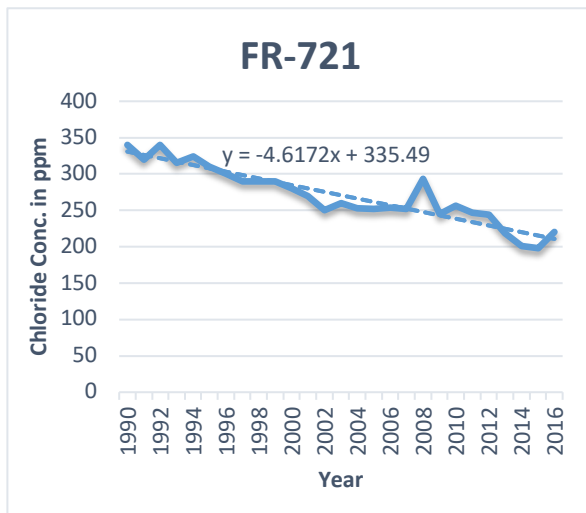


Table A3. Wells in Richland parish

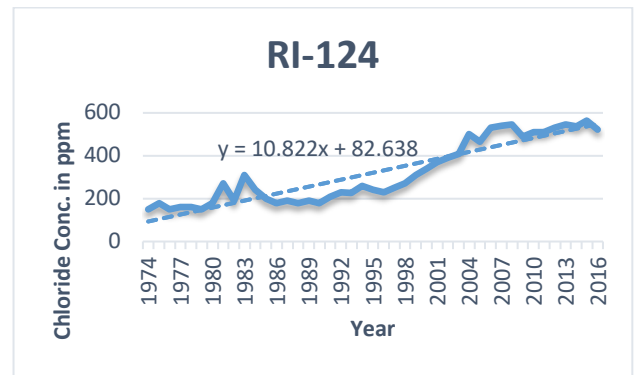
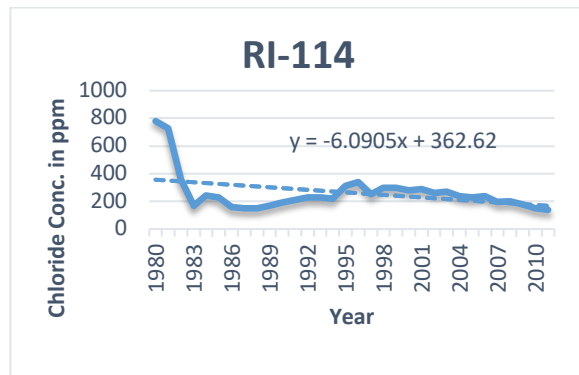


Table A4. Wells in Cameron parish

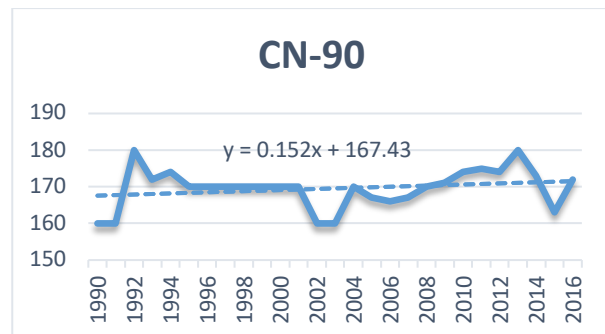
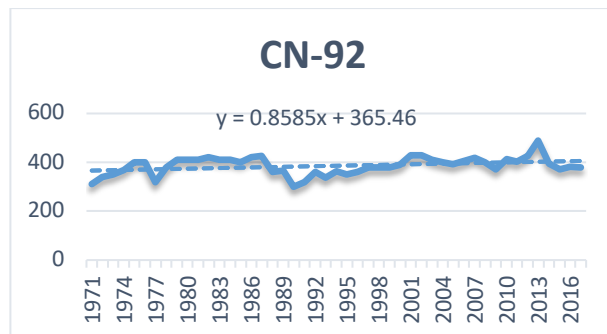
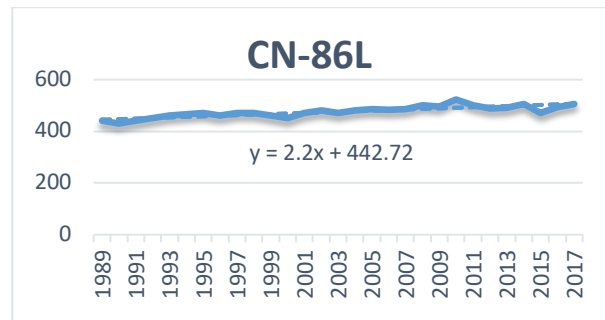
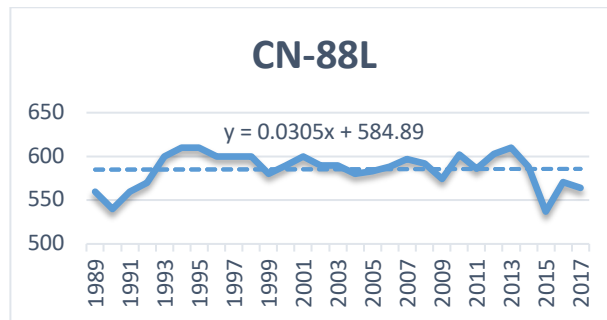


Table A5. Wells in Morehouse and Jefferson Davis parish

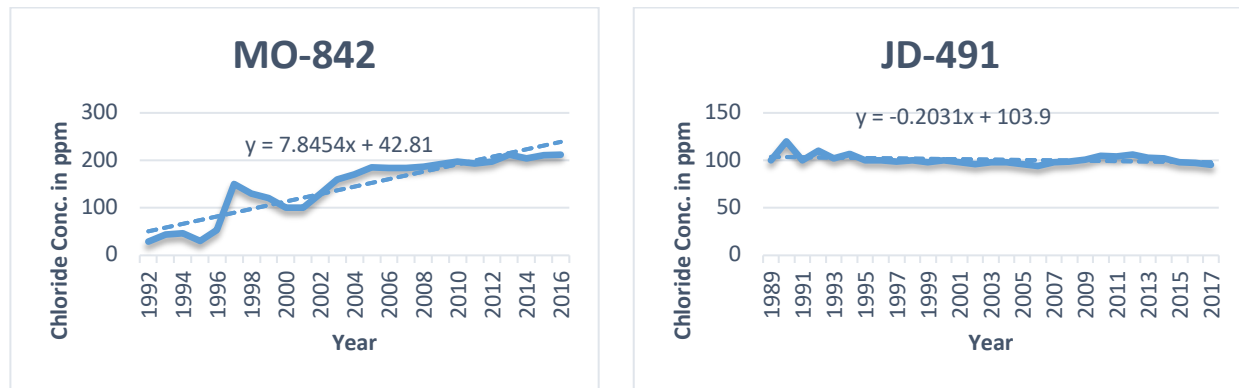


Table A6. Wells in Vermillion parish

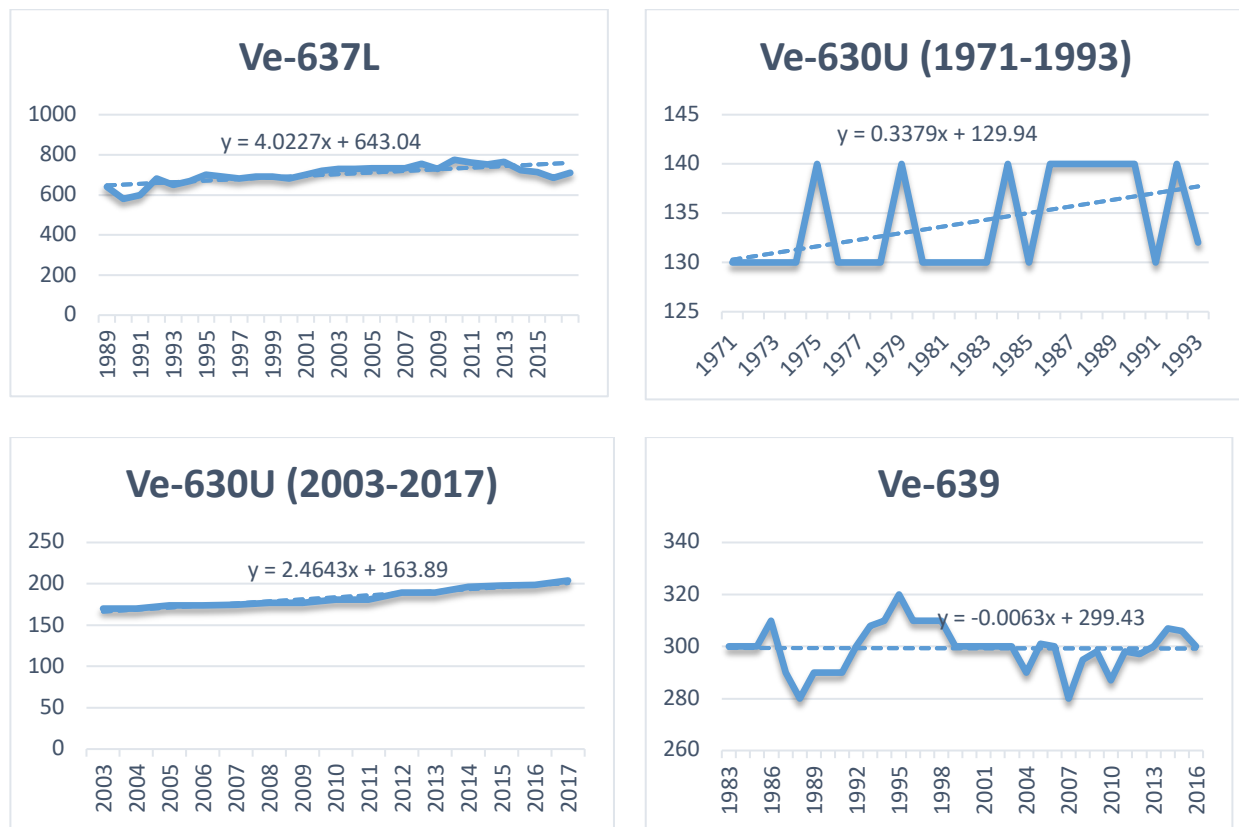
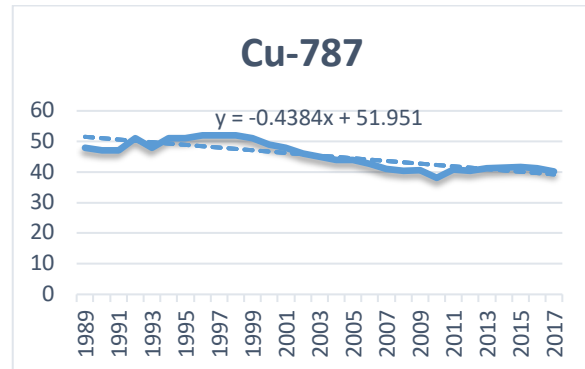
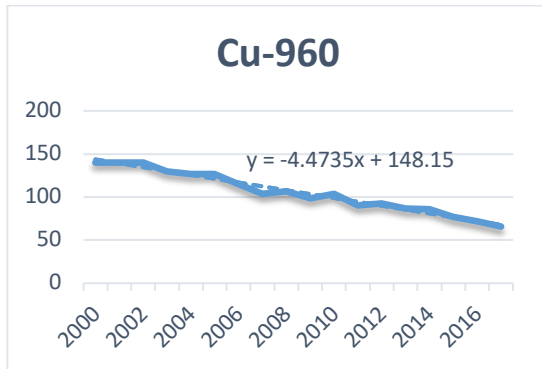


Table A7. Wells in Calcasieu parish



Appendix 2. Economic Impact Summary for Different Scenarios of Crop Production

Table 2A. Economic Impact of Salinity Induced Crop Yield Loss for Irrigated Crops: Rice, Corn and Soybeans (Medium slope, 20 years)

Impact Type	Employment	Labor Income	Total Value Added	Output
Direct Effect	530	\$ 11,814,493	\$ 21,067,366	\$ 93,553,675
Indirect Effect	286	\$ 11,519,662	\$ 18,738,653	\$ 34,357,722
Induced Effect	99	\$ 3,406,924	\$ 6,613,894	\$ 11,926,589
Total Effect	914	\$ 26,741,079	\$ 46,419,913	\$ 139,837,987
Multiplier	1.7	2.3	2.2	1.5

Table 2B. Economic Impact of Salinity Induced Crop Yield Loss for Irrigated Crops: Rice, Corn and Soybeans. (High slope, 20 years)

Impact Type	Employment	Labor Income	Total Value Added	Output
Direct Effect	1,087	\$ 36,899,460	\$ 53,976,265	\$ 207,752,864
Indirect Effect	604	\$ 24,430,319	\$ 39,576,642	\$ 72,560,487
Induced Effect	260	\$ 8,950,421	\$ 17,385,133	\$ 31,342,492
Total Effect	1,952	\$ 70,280,200	\$ 110,938,040	\$ 311,655,843
Multiplier	1.8	1.9	2.1	1.5

Table 2C. Economic Impact of Salinity Induced Crop Yield Loss for Irrigated Crops: Rice, Corn and Soybeans. (Medium slope, 30 years)

Impact Type	Employment	Labor Income	Total Value Added	Output
Direct Effect	682	\$ 15,210,495	\$ 27,123,047	\$ 120,445,088
Indirect Effect	368	\$ 14,830,916	\$ 24,124,961	\$ 44,233,632
Induced Effect	127	\$ 4,386,222	\$ 8,515,016	\$ 15,354,812
Total Effect	1,177	\$ 34,427,633	\$ 59,763,023	\$ 180,033,533
Multiplier	1.7	2.3	2.2	1.5

Table 2D. Economic Impact of Salinity Induced Crop Yield Loss for Irrigated Crops: Rice, Corn and Soybeans. (High slope, 30 years)

Impact Type	Employment	Labor Income	Total Value Added	Output
Direct Effect	1,646	\$74,654,870	\$97,656,738	\$337,846,199
Indirect Effect	941	\$38,146,915	\$61,562,275	\$112,863,348
Induced Effect	478	\$16,457,464	\$31,977,813	\$57,641,986
Total Effect	3,066	\$129,259,250	\$191,196,827	\$508,351,533
Multiplier	1.9	1.7	2.0	1.5

Table 2E: Potential Economic Impact Created Due to Crop Yield Loss When Salt Tolerant Varieties of Rice, Corn and Soybeans Are Produced on 17 parishes (High slope, 30 years)

Impact Type	Employment	Labor Income	Total Value Added	Output
Direct Effect	638	\$31,102,655	\$39,698,818	\$133,704,760
Indirect Effect	368	\$14,928,736	\$24,066,281	\$44,120,530
Induced Effect	195	\$6,715,405	\$13,049,471	\$23,521,664
Total Effect	1,202	\$52,746,796	\$76,814,571	\$201,346,954
Multiplier	1.9	1.7	1.9	1.5

Table 2F: Potential Economic Impact of Switching Irrigated Rice, Corn and Soybeans to Non-irrigated Cropping System for Same Crop or Different Crop on 17 parishes. (High slope, 30 years)

Impact Type	Employment	Labor Income	Total Value Added	Output
Direct Effect	2,359	\$262,769,738	\$232,825,829	\$579,859,352
Indirect Effect	1,368	\$57,716,248	\$89,513,646	\$164,276,558
Induced Effect	1,359	\$46,729,902	\$90,864,953	\$163,738,315
Total Effect	5,086	\$367,215,888	\$413,204,429	\$907,874,226
Multiplier	2.2	1.4	1.8	1.6

Table 2G: Potential Economic Contribution of Production of Salt Tolerant Crops (Wheat, Sorghum and Cotton) when Switched from Existing Crops: Rice, Corn and Soybeans, Under Current Scenario.

Impact Type	Employment	Labor Income	Total Value Added	Output
Direct Effect	3,453	\$209,827,462	\$255,672,329	\$574,331,016
Indirect Effect	1,409	\$63,558,698	\$96,551,160	\$174,800,227
Induced Effect	1,159	\$39,932,083	\$77,482,741	\$139,751,193
Total Effect	6,021	\$313,318,243	\$429,706,229	\$888,882,436
Multiplier	1.7	1.5	1.7	1.5

Table 2H: Potential Economic Contribution of Production of Salt Tolerant Crops (Wheat, Sorghum and Cotton) when Switched from Existing Crops: Rice, Corn and Soybeans. (Under High Salinity Slope Condition in 30 Years)

Impact Type	Employment	Labor Income	Total Value Added	Output
Direct Effect	3,435	\$209,418,501	\$254,943,078	\$571,092,640
Indirect Effect	1,399	\$63,159,943	\$95,902,518	\$173,610,929
Induced Effect	1,155	\$39,814,151	\$77,253,800	\$139,338,352
Total Effect	5,989	\$312,392,596	\$428,099,396	\$884,041,921
Multiplier	1.7	1.5	1.7	1.5

Vita

Rajan Dhakal, a native of Chitwan, Nepal, received his Bachelor of Science in Agriculture from Tribhuvan University, Nepal in 2016. Upon completion of his undergraduate studies, he decided to further his education and pursue a higher degree. He was accepted into the LSU graduate school to major in Agricultural Economics. He anticipates graduating with his Master of Science degree in December 2018 and plans to pursue a career in Agricultural Economics.